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DESCRIPTION AND EVALUATION OF A DIGITAL-COMPUTER PROGRAM FOR CALCULATING THE VISCOUS DRAG OF BODIES OF REVOLUTION

by

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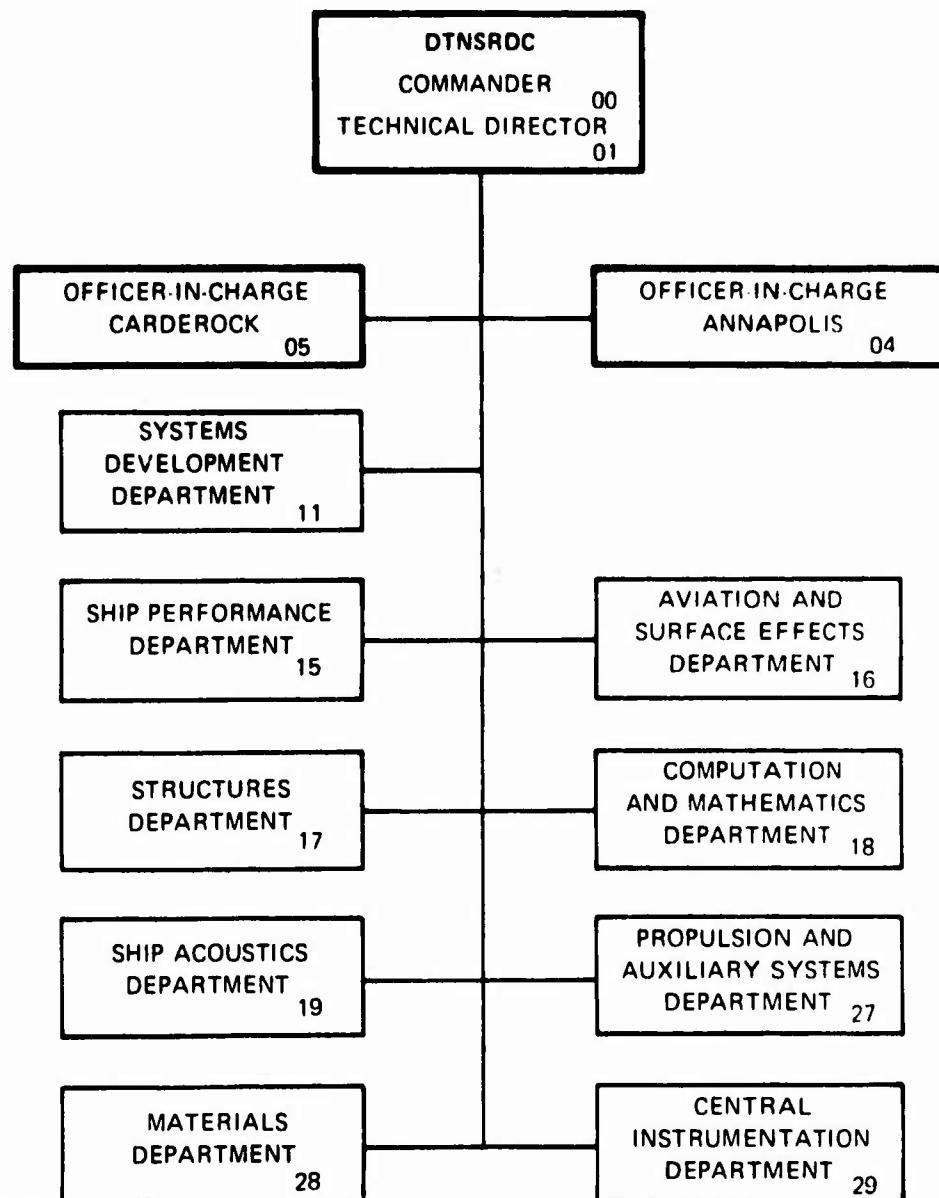
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A digital-computer program has been written for calculating the viscous drag of streamlined bodies of revolution in constant-density axial flow. The integral approach adopted incorporates recently improved methods for predicting the transition point and for calculating the turbulent boundary layer. The inputs to the computer program are the body geometry, the

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associated inviscid pressure distribution, and the body-length Reynolds
number. Agreement of calculated and measured drag coefficients is good,
particularly in cases where the transition point is predicted accurately.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

A digital-computer program has been written for calculating the viscous drag of streamlined bodies of revolution in constant-density axial flow. The integral approach adopted incorporates recently improved methods for predicting the transition point and for calculating the turbulent boundary layer. The inputs to the computer program are the body geometry, the associated inviscid pressure distribution, and the body-length Reynolds number. Agreement of calculated and measured drag coefficients is good, particularly in cases where the transition point is predicted accurately.

ADMINISTRATIVE INFORMATION

INTRODUCTION

The accurate prediction of the viscous drag of streamlined bodies of revolution in steady axial motion in a constant-density fluid is a basic hydrodynamic problem of great importance to designers. A streamlined body is defined here as one on which there is no significant flow separation; thus such configurations as those with very blunt sterns or noses are excluded. In 1953 Granville[1] reported a method of calculating viscous drag based on momentum-integral formulations of the laminar- and turbulent-boundary-layer equations. The method of predicting the transition point was based on a correlation of two-dimensional airfoil data in terms of the difference between the momentum-thickness Reynolds numbers at the transition and neutral-stability points and the averaged

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[1]Granville, P. S., "The Calculation of the Viscous Drag of Bodies of Revolution," David Taylor Model Basin Report 849 (Jul 1953). A complete listing of references is given on page 141.

1

pressure-gradient parameters between these two points. The turbulent-boundary-layer calculations were based on power-law relations which result in simple quadratures. The calculations were separated into two parts, according to whether the boundary layer was thick or thin relative to the local body radius.

The updated method of drag prediction described herein follows that of Granville[1] in outline. The laminar-boundary-layer calculations are unchanged. The transition point is found from a new correlation of transition data for bodies of revolution in terms of the difference between the momentum-thickness Reynolds numbers at the transition and neutral-stability points and the rate of change of body shape. This new correlation was obtained by Granville[2] and applies to curved bodies; as an alternative, the method of transition prediction obtained earlier by Granville[1] and applied by Smith[3] can be used. The turbulent-boundary-layer calculations are made from two "integral" differential equations, a momentum equation and a shape-parameter equation based on entrainment. The new method is developed by Granville[4] and incorporates velocity-similarity laws. It applies to either thick or thin boundary layers and so it is not necessary to give separate consideration to the region near the tail where the boundary layer is thick.

A digital-computer program has been written to execute the calculations and compute the drag. A preliminary program is used to compute the body shape from a specified polynomial description; this is used as input to the Douglas-Neumann potential-flow program which calculates the inviscid pressure distribution for use in the boundary-layer calculations.

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[2]Granville, P. S., "The Prediction of Transition from Laminar to Turbulent Flow in Boundary Layers on Bodies of Revolution," NSRDC Report 3900 (Sep 1974); also presented at the Tenth Office of Naval Research Symposium on Naval Hydrodynamics, Massachusetts Institute of Technology, Cambridge, Mass. (Jun 1974) and will appear in the proceedings of this symposium.

[3]Smith, A. M. O., Discussion of Granville symposium paper[2]; will appear in the symposium proceedings.

[4]Granville, P. S., "Similarity-Law Method for Thick Axisymmetric Turbulent Boundary Layers in Pressure Gradients," DTNSRDC Report 4525 (in preparation).

Comparison of the computed results with towing-tank measurements shows
(1) that the accuracy of the two Granville methods for predicting transi-
tion is roughly equal if transition occurs on the forebody and (2) that
the drag is predicted accurately if the transition prediction is accurate.
The turbulent-boundary-layer theory on which the calculations are based
includes the Schoenherr frictional line; the program can be forced to
reproduce the Schoenherr line as its predicted drag coefficient by
setting the pressure gradient equal to zero, setting the body radius
equal to a constant sufficiently large value, and forcing transition at
the nose. Granville uses the Schoenherr line as a baseline for his
method because of its classical and scientific importance in turbulent-
boundary-layer theory. In the figures in this report which present
calculations done by this theory, the Schoenherr line has been drawn in
for comparison; it is an easy matter to draw in other lines which are in
widespread use, such as the 1957 International Towing Tank Conference
correlation line for ship models.

A method for predicting the viscous drag of a body of revolution
has also been reported by Nakayama and Patel.[5] It is similar to the
method of Granville reported here in that an entrainment equation is
used (but with a more restricted one-parameter system) and in that
careful consideration is given to the region near the tail where the
boundary layer is thick. Four alternative methods of predicting the
transition point are available, one of which is that of Granville.[1]
Good agreement with measured results is reported.

A second method, reported by Cebeci, Mosinskis, and Smith,[6] uses
the more time-consuming differential formulation of the boundary-layer
equations, with an eddy-viscosity profile. These authors provide two
alternative methods for predicting transition, one of which is that of
Granville.[1] Again, good agreement with measured results is reported.

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[5]Nakayama, A. and V. C. Patel, "Calculation on the Viscous Resistance
of a Body of Revolution," Journal of Hydronautics, Vol. 8, No. 4,
pp. 154-162 (Oct 1974).

[6]Cebeci, T. et al., "Calculation of Viscous Drag in Incompressible
Flows," Journal of Aircraft, Vol. 9, No. 10, pp. 691-692 (Oct 1972).

3

Parsons, Goodson, and Goldschmied[7] used the method of Cebeci et al.[6] together with an optimum-search strategy to find the body of revolution which has minimum drag for specified speed and enclosed volume. Their approach is to find a shape which has transition as far downstream as possible at the specified speed. Good agreement with measured results is reported.

Following recent German methods described by Lugt and Oh,[8] Oh and Reingruber* have used an integral formulation of the boundary-layer equations and a transition criterion different from those reported here to compute the viscous drag on a number of bodies of revolution. The only comparison with measured results provided is for the transition point on one body, and fairly good agreement was obtained in that instance.

DESCRIPTION OF DIGITAL-COMPUTER PROGRAM

The digital-computer program which is the subject of this section of the report predicts the viscous drag on a streamlined body of revolution according to the boundary-layer theory developed by Granville.[1,4] The program actually consists of three distinct programs; if desired, the execution of one of these can be partially repeated and the execution of a second can be completely repeated for each body and length Reynolds number R_L. These three programs are as follows:

DPIN   This program computes the shape (offsets, slopes, etc.) of the body of revolution on the basis of geometric parameters which are input in accordance with polynomials developed by Granville. At present three alternative DPIN's are available (DPIN1, DPIN2, and DPIN3) for three

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[7]Parsons, J. S. et al., "Shaping of Axisymmetric Bodies of Minimum Drag in Incompressible Flows," Journal of Hydronautics, Vol. 8, No. 3, pp. 100-107 (Jul 1974).

[8]Lugt, H. J. and S. K. Oh, "Boundary-Layer Suction with Slots on Axisymmetric Bodies," NSRDC Report 4038 (Nov 1972).

*As reported informally in NSRDC Technical Note CMD-30-73 dated September 1975.

different classes of bodies; the user may create addi-
tional alternatives for other class of bodies. In this
report, when DPIN is mentioned, it is to be understood
that the particular DPIN is meant which describes the
body being treated. Appendixes A-C provide descriptions
of the respective DPIN's.

DA50   This is the Douglas-Neumann program developed by Smith,
Hess, and their associates for computing inviscid sub-
sonic flow about a body of revolution. It represents the
body by a series of frustums of cones, with axes along
the axis of symmetry, and it assumes a constant (unknown)
hydrodynamic source strength on each frustum. The
boundary-value problem for the Laplace equation with the
boundary condition of zero normal velocity on the body
leads to a Fredholm integral equation of the second kind.
This is solved as a set of linear algebraic equations by
using (in the option selected here) Seidel iteration.
The velocity potential, velocity components, and pressure
anywhere in the flow field can be found relatively easily
after the distribution of source strength on the body is
determined.

DPOUT This program computes the boundary layer on the body and
the viscous drag, using the shape computed by DPIN and
the inviscid velocity distribution computed by DA50. It
also computes the boundary-layer displacement thickness
and relates an increment in hydrodynamic source strength
to the (inviscid) velocity and the displacement thickness.
Then, if desired, the program can go back to the end of
DA50, add in the increment in source strength, recompute
the velocity distribution, return to DPOUT, and recompute
the boundary layer to give a more accurate prediction.

In principle this iteration could be repeated until some convergence criterion is satisfied; however, in its present form, the program recomputes the boundary layer only once. The advantage of this method for incorporating the effect of displacement thickness is that the return to DA50 is at a point following the time-consuming Seidel iteration. Thus this iteration need be executed only once for a given body of revolution even though the boundary layer is computed at several R_L's, each of which would correspond to a different displacement thickness. Appendix D provides descriptions of DA50 and DPOUT.

Figure 1 illustrates a representative body of revolution with its boundary layer in the coordinate system used in the calculations.

CALCULATION OF LAMINAR BOUNDARY LAYER

The method by which the laminar boundary layer is calculated has been described by Granville.[1] For the case of zero pressure gradient, the integral method used reduces to the Blasius flat-plate relation. The possibility of laminar separation is considered according to the criterion of Thwaites.[9] The increment in source strength used to represent displacement thickness is calculated according to Lighthill.[10]

The method begins by calculating the pressure-gradient parameter $\frac{\theta^2}{\nu} \frac{dU}{ds}$; where θ, $\frac{dU}{ds}$, and ν are the dimensional momentum thickness, velocity gradient, and kinematic viscosity at points along the laminar boundary layer. The FORTRAN name for $\frac{\theta^2}{\nu} \frac{dU}{ds}$ in DPOUT is PGI. Equation (52) in Granville[1] gives

[9]Thwaites, B., "Approximate Calculation of the Laminar Boundary Layer," Aeronautical Quarterly, Vol. I, Part III, pp. 245-280 (Nov 1949).

[10]Lighthill, M. J., "On Displacement Thickness," Journal of Fluid Mechanics, Vol. 4, Part 4, pp. 383-392 (Aug 1958).

POTENTIAL FLOW

TRANSITION

TURBULENT

LAMINAR

VISCOUS FLOW

STAGNATION
POINT U = 0

TAIL   WAKE   X

U = 1   NOSE $\mathcal{C}_L$

S

1

$\dfrac{dp}{ds} < 0$ FAVORABLE

PRESSURE.
GRADIENT

$\dfrac{dp}{ds} > 0$ ADVERSE PRESSURE GRADIENT

BOUNDARY LAYER

$\dfrac{dp}{ds} = 0$

U = MAX
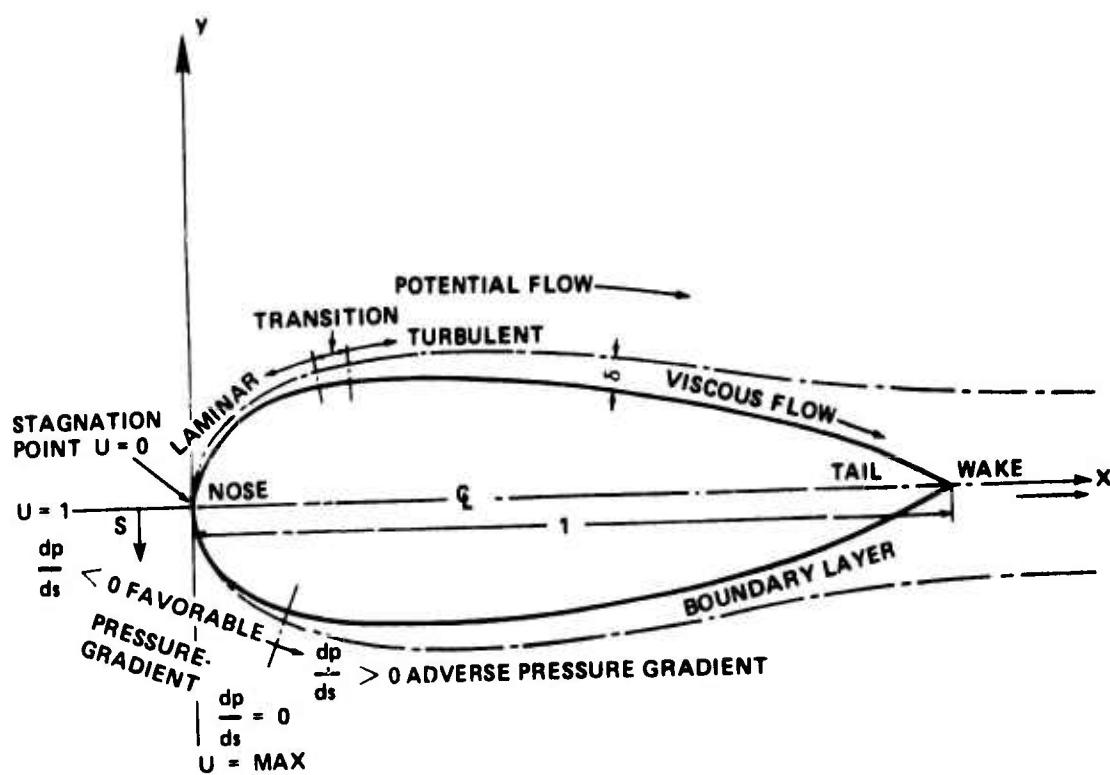
Figure 1 — Body of Revolution with Regions of Potential, Boundary-Layer,
and Wake Flows Indicated

(Adapted from Figure 1 of Granville[1])

$$\frac{\theta^2}{\nu}\frac{dU}{ds} = \frac{R_\theta^2}{R_L}\frac{1}{(U/U_\infty)^2}\frac{1}{\sec\alpha}\frac{d(U/U_\infty)}{d(x/L)} \tag{1}$$

where R_θ is the Reynolds number based on U and θ and R_θ^2/R_L is given by Equation (51) in Granville[1] as

$$\frac{R_\theta^2}{R_L} = \frac{4}{9}\frac{\beta}{(U/U_\infty)^2(y/L)^2} \tag{2}$$

with

$$\beta = \int_0^{x/L}\left[\frac{U}{U_\infty}\left(\frac{x'}{L}\right)\right]^5\left[\frac{y}{L}\left(\frac{x'}{L}\right)\right]^2\sec\left[\alpha\left(\frac{x'}{L}\right)\right]d\left(\frac{x'}{L}\right) \tag{3}$$

R_θ^2/R_L and β have the FORTRAN names RTH2RL and B in DPOUT. According to Thwaites,[9] laminar separation takes place at the point where $\frac{\theta^2}{\nu}\frac{dU}{ds}$ first becomes less than or equal to -0.09.

The Blasius flat-plate shear-stress coefficient C_f (named CF in DPOUT) is given by

$$C_f = \frac{2\pi}{A^{(t)}}\int_0^x y(x')\,C_\tau(x')\,dx' \tag{4}$$

Here $A^{(t)}$ is total area, $C_\tau(x) = \frac{0.664}{\sqrt{R_s}}$, and R_s is the Reynolds number based on U_∞ and distance s along the body surface. (The axial component of C_τ is $C_\tau\cos\alpha$ and the element of integration is ds or $\sec\alpha\,dx$.)

The increment in source strength needed to represent the effect of displacement area Λ^*, defined as

$$\Lambda^* = \int_0^\delta \left(1 - \frac{u}{U}\right) y \, dn \qquad (5)$$

(δ is boundary layer thickness and n is coordinate normal to surface) is, according to Lighthill,[10]

$$\sigma = \frac{\sec \alpha}{2 \pi y} \frac{d}{dx} (U\delta^*) \qquad (6)$$

Here σ is the source strength per unit area normalized such that the velocity potential due to a fundamental source Σ at a point x_o, y_o, z_o is

$$\phi(x,y,z) = - \frac{\Sigma}{\sqrt{(x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2}} \qquad (7)$$

For the laminar boundary layer, the power-law profile assumed in Granville[1] gives

$$\Lambda^* = 3 \, \Omega \qquad (8)$$

where Ω is the momentum area defined by

$$\Omega = \int_0^\delta \left(1 - \frac{u}{U}\right) \frac{u}{U} y \, dn \qquad (9)$$

(δ and n are defined under Equation (5)). Equation (35) in Granville[1] is

$$\Omega = y \, \theta \qquad (10)$$

9

so

$$\Omega = \frac{y \, R_\theta \, \nu}{U}$$

$$= y \, L \, \frac{R_\theta}{R_L} \frac{U_\infty}{U}$$

or

$$\frac{\Omega}{L^2} = \frac{y}{L} \frac{R_\theta}{R_L} \frac{U_\infty}{U} \tag{11}$$

R_θ is found as the square root of R_L times the right-hand side of Equation (2), and Ω/L^2, denoted by OML2 in DPOUT, is given by Equation (11). Equation (8) gives $\Lambda*/L^2$ (ELSL2 in DPOUT) and Equation (6) gives

$$\frac{\sigma}{U_\infty} = \frac{\sec \alpha}{2 \, \pi} \frac{L}{y} \left[\frac{\Lambda*}{L^2} \frac{d(U/U_\infty)}{d(x/L)} + \frac{U}{U_\infty} \frac{d(\Lambda*/L^2)}{d(x/L)} \right] \tag{12}$$

$\dfrac{d(U/U_\infty)}{d(x/L)}$ has been calculated near the beginning of DPOUT; the differentiating subroutine DGT3 is used[11] to calculate $\dfrac{d(\Lambda*/L^2)}{d(x/L)}$. The quantity $\dfrac{\sigma}{U_\infty}$ is denoted by DELSIG in DPOUT. Calculation of DELSIG is omitted when execution of DPOUT is carried through the second time for a given configuration and R_L (through use of the control variable ICONTROL) since there is no further need for it. More precise values of the source strength are not needed since no further executions of DPOUT are performed.

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[11] "360 Scientific Subroutine Package, Version III," IBM Reference Manual, Serial H-20-0205-3, p. 319 (1968).

Actual calculation of $\frac{\sigma}{U_\infty}$ by using Equation (12) is not performed

in the laminar-boundary-layer part of DPOUT unless no turbulent boundary

layer is reached on the body due to very small values of R_L. Values of

$\frac{\Lambda*}{L^2}$ are calculated by using Equations (11) and (8), and $\frac{\sigma}{U_\infty}$ is found from

Equation (12) at the end of the turbulent-boundary-layer calculations.

Equation (2.1) in Hess and Smith[12] shows that the fundamental

source strength in the Douglas-Neumann programs is the negative of

Equation (7). Therefore, the calculated DELSIG must be subtracted

from rather than added to the calculated source strength in LINK 6 of

DA50.

In order to find the neutral-stability point, the curve of R_θ

versus $\frac{\theta^2}{\nu} \frac{dU}{ds}$ (Figure 3 in Granville[1]) is approximated by a cubic in

$\frac{\theta^2}{\nu} \frac{dU}{ds}$. This figure and the numerical approximation to it are shown as

Figure 2. The neutral-stability point is found by comparing R_θ with

the function of $\frac{\theta^2}{\nu} \frac{dU}{ds}$ described by the line in Figure 2 or by the cubic in

the program, starting at the nose of the body. The neutral-stability

point is assumed to be the point nearest the nose at which R_θ equals or

exceeds the function of $\frac{\theta^2}{\nu} \frac{dU}{ds}$.

After the neutral stability point is found, the laminar-boundary-

layer calculations are continued. $\frac{\theta^2}{\nu} \frac{dU}{ds}$, R_θ, Ω/L^2, $\Lambda*/L^2$, and C_f are

found at each point. A function of body geometry, $\frac{D_o}{L} \frac{L}{y} \frac{d(y/L)}{d(x/L)}$, which is

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[12]Hess, J. L. and A. M. O. Smith, "Calculation of Potential Flow
about Arbitrary Bodies," in "Progress in Aeronautical Sciences,"
Pergamon Press, Oxford and New York, Vol. 8, (1966), pp. 1-138.
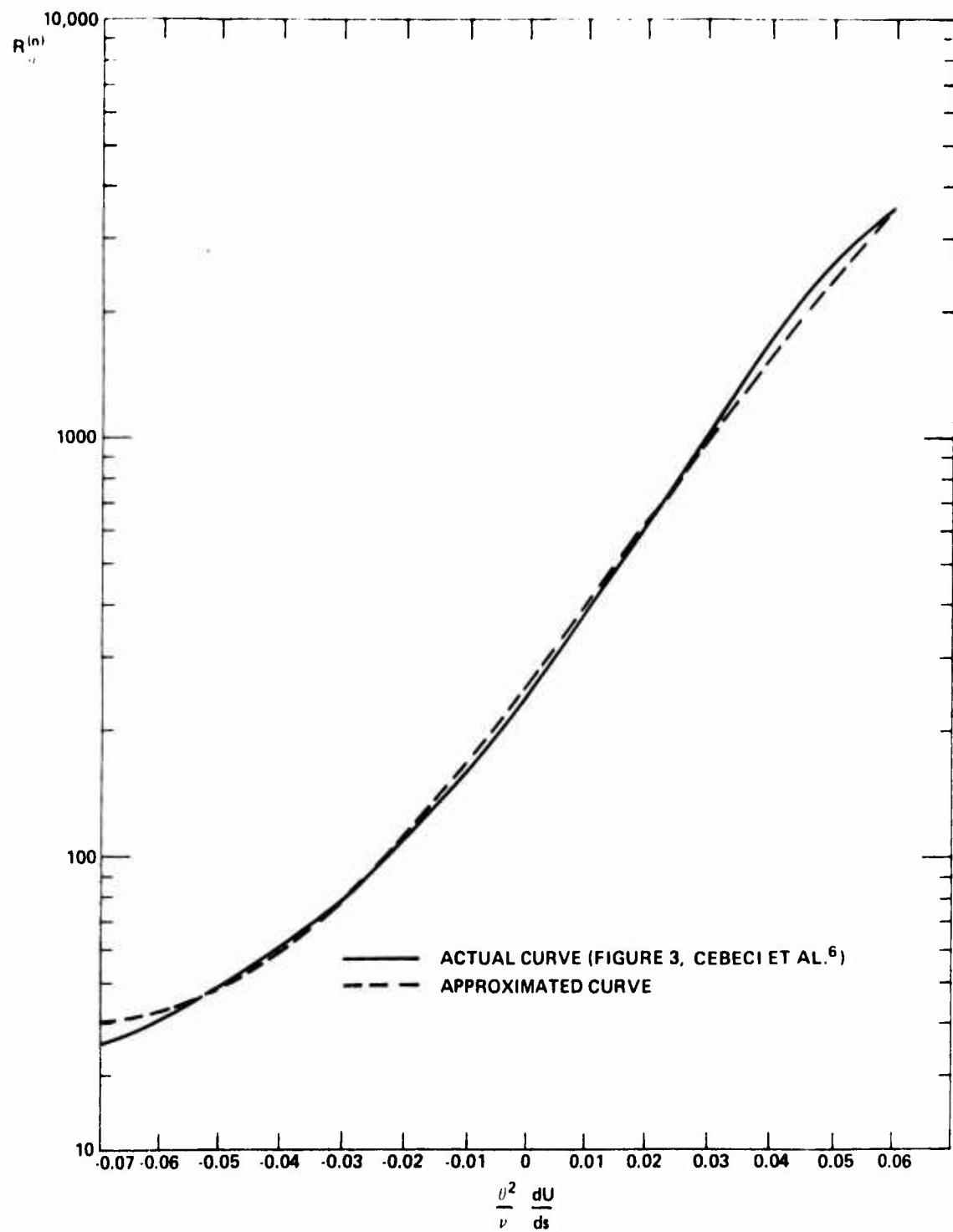
Figure 2 – Curve for Calculating $R_\theta^{(n)}$ as a Function of $\frac{\theta^2}{\nu} \frac{dU}{ds}$ and Numerical Approximation to This Curve

denoted by TP, is also calculated at each point downstream of the neutral-stability point. (D_o is maximum body diameter.) TP will be needed if the transition point is to be calculated according to the 1974 method of Granville.[2] A second function of body geometry, denoted by D, and given by

$$D = \int_{(x/L)^n}^{x/L} \left[\frac{y}{L} \left(\frac{x'}{L} \right) \right]^2 \sec \left[\alpha \left(\frac{x'}{L} \right) \right] d \left(\frac{x'}{L} \right) \qquad (13)$$

is also calculated at each point downstream of the neutral-stability point. D will be needed if the transition point is to be calculated according to the 1953 method of Granville.[1]

CALCULATION OF TRANSITION POINT

This section describes two methods for calculating the point where there is a natural transition from laminar- to turbulent-boundary-layer flow. It is to be understood that natural transition may not be reached because forced transition takes place upstream of it, either (1) at a transition trip at a point XTRIP if ITRIP is set equal to 1 or (2) at the laminar separation point if ITLS is set equal to 1.

Granville 1974 Method

This method computes R_θ and TP at each point downstream of the neutral-stability point and predicts transition at the point where $R_\theta - R_\theta^{(n)}$ first exceeds a particular polynomial function of TP, designated by TF. The polynomial is selected by using control variables J and L as input. J is set equal to 1 if and only if it is desired to use a numerical approximation to the low-background-turbulence curve shown as Figure 16 in Granville,[2] together with one of two extensions of it (selected by L) for large positive values of TP. These are shown in Figure 3 along with the high-background-turbulence curve which is

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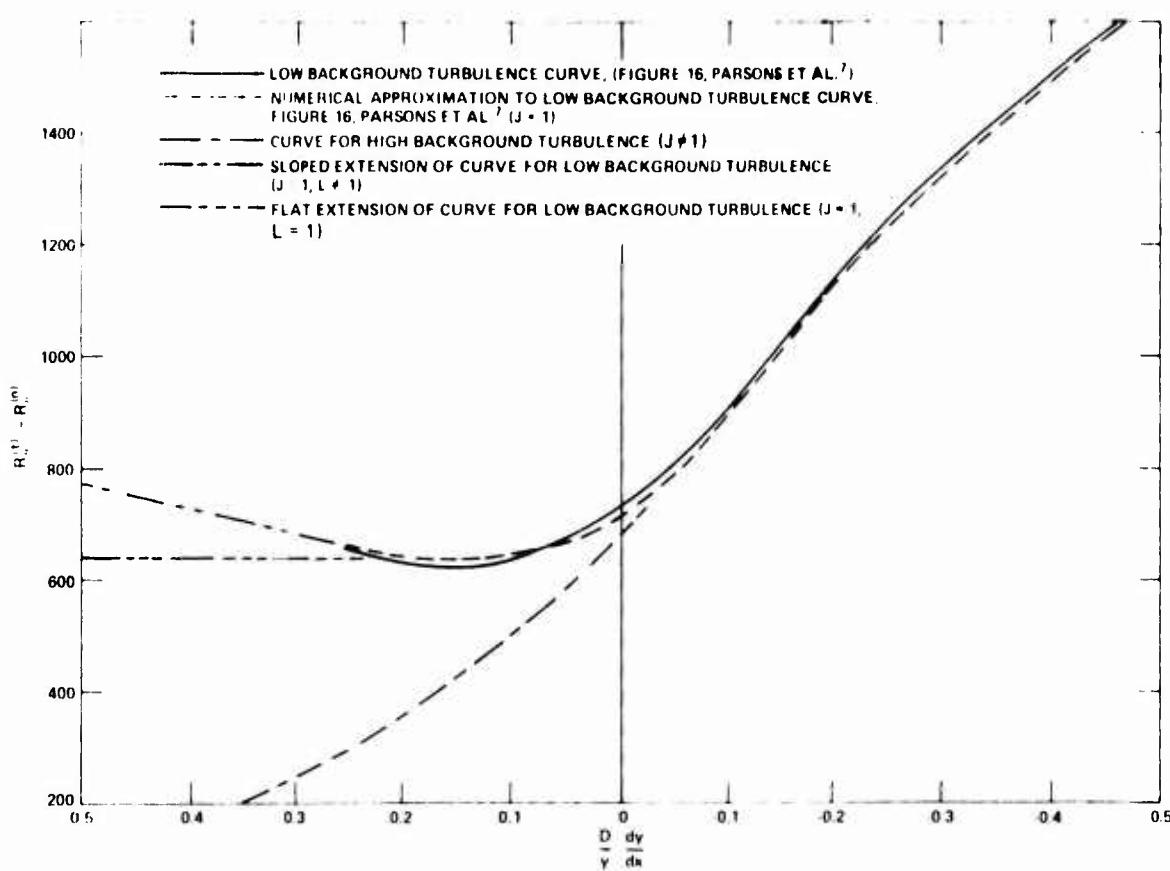
Figure 3 – Curves for Calculating $R_\theta^{(t)} - R_\theta^{(n)}$ as a Function of $\dfrac{D}{y} \dfrac{dy}{dx}$ and Numerical Approximations to These Curves

14

selected if J is not equal to 1. The polynomial representations of these curves or TF's are given below.

J	L	TP Range	TF
1	1 or $\neq$ 1	$TP < 0.075$	$671.8 - 2432.4 \cdot TP - 930.4 \cdot TP^2$
1	1	$-0.75 \leqslant TP < 0.165$	$719. - 1253. \cdot TP + 5857.9 \cdot TP^2 - 7287.7 \cdot TP^3$
1	1	$0.165 \leqslant TP$	$639.$
1	$\neq$ 1	$0.075 \leqslant TP < 0.25$	$719. - 1253. \cdot TP + 5857.9 \cdot TP^2 - 7287.7 \cdot TP^3$
1	$\neq$ 1	$0.25 \leqslant TP$	$551. + 428. \cdot TP$
$\neq$ 1	1 or $\neq$ 1	$TP < 0.02$	$671.8 - 2432.4 \cdot TP - 930.4 \cdot TP^2$
$\neq$ 1	1 or $\neq$ 1	$0.02 \leqslant TP$	$681.4 - 1910.38 \cdot TP + 1233.6 \cdot TP^2 + 1036.5 \cdot TP^3$

In the concluding section, Granville[2] emphasized that the method of calculating the transition point is based on empirical data for bodies which do not have significant adverse pressure gradients; on a parallel middlebody TP is zero and TF is either 719.0 or 681.4, depending on whether J is equal to 1. Consequently $R_\theta^{(t)}$, the value of R_θ at transition, is equal to $R_\theta^{(n)}$ plus a constant for any transition point on the parallel middlebody. This is too restrictive to be physically realistic. Nevertheless, the method has been used successfully with bodies which have parallel middlebodies in cases where R_L is large enough so that transition occurs on the forebody. These cases will be discussed later in this report.

Granville 1953 Method

If it is desired to use the method of calculating the transition point described by Granville in 1953,[1] the control variable I53 should be set equal to 1. The method predicts transition at the first point where the equivalent two-dimensional R_θ, designated by superscript $\tilde{\ }$, exceeds its value at the neutral-stability point plus $450 + 400 \, e^{60\bar{\lambda}}$ where $\bar{\lambda}$ is given by

$$\bar{\lambda} = \frac{1}{5}\left[\frac{4}{9} - \frac{\dfrac{(R_\theta\, y/L)^2}{R_L\, U/U_\infty} - \dfrac{(R_\theta^{(n)}\, y^{(n)}/L)^2}{R_L\, U^{(n)}/U_\infty}}{D}\right] \tag{14}$$

The superscript n means that quantities are to be evaluated at the neutral-stability point, and D is given by Equation (13). The equivalent two-dimensional R_θ is given by

$$\tilde{R}_\theta = \frac{y}{D/2}\, R_\theta$$

where D is the maximum diameter. This method of predicting transition can be used on parallel middlebodies.

The form in which this transition-prediction method is used is one suggested by Smith[3] based on a curve fit used by White[13] (see Equation (5-51) in White) to describe data presented in Equation (53) and Figure 4 of Granville.[1]

CALCULATION OF TURBULENT BOUNDARY LAYER

The method by which the turbulent boundary layer is calculated is described in Granville.[4] It is a two-parameter similarity-law integral method which does not require the boundary layer to be thin compared with the body radius, and thus it is valid near the tail of an axisymmetric body. The equations needed for the calculations are repeated below. It should be emphasized that the method assumes that θ (and hence R_θ) is continuous through the transition point.

$H^{(t)}$, the shape parameter at transition, is found from the flat-plate equation

$$H^{(t)} = \frac{1}{1 - \dfrac{1}{0.617 + 0.3863\,\log_e R_\theta}} \tag{15}$$

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[13]White, F. M., "Viscous Fluid Flow," McGraw-Hill Book Company, New York (1974), pp. 441-444.

At points downstream from transition, σ (defined by $\sigma = \sqrt{2/C_f}$ where C_f is the local skin-friction coefficient) is found from the transcendental equation

$$\frac{0.3462\ (3.889 - H)}{H}\ \sigma + 2.448\ \log_e \sigma = 2.606\ \log_e R_\theta - 1.456$$
$$- 2.606\ \log_e \frac{(H - 1)^{0.9392}}{H^{1.9392}}$$

(16)

G, the Rotta shape parameter, is given by

$$G = \sigma\ \frac{H - 1}{H}$$

(17)

$\tilde{H}$, the entrainment shape parameter is given by

$$\tilde{H} = \frac{H^2}{H - 1}\ \left(1.4857 + \frac{1.235}{G} + \frac{33.96}{G^{2.75}}\right)\ - H$$

(18)

and $\beta^{(e)}$ is given by

$$\beta^{(e)} = \left(\frac{G + 1.6}{6.1}\right)^2 - 1.81$$

(19)

After the above quantities have been found at a given point, the reduced entrainment factor $\hat{E}$ is found from

$$\hat{E} = \left(\beta^{(e)}\ \frac{H + 1}{H} + 1\right)\left(\tilde{H} + \frac{\partial \tilde{H}}{\partial \log_e R_\theta}\right) - \frac{\partial \tilde{H}}{\partial H}\ \frac{H + (H + 1)\ \beta^{(e)}}{1 + \dfrac{G\ H}{2.606\ (H - 1)^2}}$$

(20)

17

E, the entrainment factor, is given by

$$E = \frac{\hat{E}}{\sigma^2} \qquad (21)$$

H_ϕ, the quadratic momentum-shape parameter, is given by

$$H_\phi = \frac{0.1028\ H^2\ (H + 3.336)}{H - 1} + \frac{1}{\sigma}\ \frac{0.4746\ H^3}{H - 1} + \frac{1}{\sigma^3}\ \frac{7.818\ H^6}{(H - 1)^4} \qquad (22)$$

and the quadratic displacement-shape parameter H_Δ is found from

$$H_\Delta = \frac{0.4457\ H^3}{H - 1} + \frac{H^6}{\sigma^3}\ \frac{7.818}{(H - 1)^4} \qquad (23)$$

The two boundary-layer parameters H and R_θ (or $\log_e R_\theta$) play the roles of independent variables in these calculations. Derivatives of $\log_e \sigma$, $\tilde{H}$, H_ϕ, and H_Δ with respect to H and $\log_e R_\theta$ will be needed in the calculations. It is seen from Equations (16), (18), (22), and (23) that these are given by the following equations:

$$\frac{1}{\sigma}\ \frac{\partial \sigma}{\partial H} = \frac{2.8885}{H(H - 1)}\ \frac{1.3469\ (H - 1)\sigma + 2.606\ H(H - 1.9392)}{(3.889 - H)\sigma + 7.07\ H} \qquad (24)$$

$$\frac{1}{\sigma}\ \frac{\partial \sigma}{\partial\ (\log_e R_\theta)} = \frac{7.527\ H}{(3.889 - H)\sigma + 7.07\ H} \qquad (25)$$

$$\frac{\partial \tilde{H}}{\partial H} = \frac{\tilde{H}(H - 2) - H}{H(H - 1)} - \frac{H^2}{H - 1}\ \left(\frac{1.235}{G} + \frac{93.39}{G^{2.75}} \right) \left[\frac{1}{H(H - 1)} + \frac{1}{\sigma}\ \frac{\partial \sigma}{\partial H} \right]$$

$$(26)$$

$$\frac{\partial \tilde{H}}{\partial (\log_e R_\theta)} = - \frac{H^2}{H - 1} \left(\frac{1.235}{G} + \frac{93.39}{G^{2.75}} \right) \frac{1}{\sigma} \frac{\partial \sigma}{\partial (\log_e R_\theta)} \qquad (27)$$

$$\frac{\partial H_\phi}{\partial H} = \frac{0.1028\, H\, (2\, H^2 + 0.336\, H - 6.672)}{(H - 1)^2} - \frac{2.606\, H^3}{H - 1} \left\{ \frac{0.1821}{\sigma} \right.$$

$$+ 9 \left[\frac{H}{\sigma(H - 1)} \right]^2 \left. \right\} \frac{1}{\sigma} \frac{\partial \sigma}{\partial H} + \frac{0.4746\, H^2\, (2\, H - 3)}{(H - 1)^2\, \sigma}$$

$$+ \frac{15.636\, (H - 3)}{\sigma^3} \left(\frac{H}{H - 1} \right)^5 \qquad (28)$$

$$\frac{\partial H_\phi}{\partial (\log_e R_\theta)} = - \left[\frac{0.4746\, H^3}{(H - 1)\sigma} + \frac{23.45}{(H - 1)^4} \frac{H^6}{\sigma^3} \right] \frac{1}{\sigma} \frac{\partial \sigma}{\partial (\log_e R_\theta)} \qquad (29)$$

$$\frac{\partial H_\Delta}{\partial H} = 0.4457\, (2\, H - 3) \left(\frac{H}{H - 1} \right)^2 - \frac{23.45}{(H - 1)^4} \frac{H^6}{\sigma^3} \frac{1}{\sigma} \frac{\partial \sigma}{\partial H}$$

$$+ 15.636\, \frac{H - 3}{\sigma^3} \left(\frac{H}{H - 1} \right)^5 \qquad (30)$$

and

$$\frac{\partial H_\Delta}{\partial (\log_e R_\theta)} = - \frac{23.45}{H - 1} + \frac{H^6}{\sigma^3} \frac{1}{\sigma} \frac{\partial \sigma}{\partial (\log_e R_\theta)} \qquad (31)$$

The order in which these equations are solved at each point downstream of transition is as follows. With H and R_θ known, Equation (16) is solved for σ. Then, in order, Equation (17) is solved for G, Equation (18) is solved for $\tilde{H}$, Equation (24) is solved for $\frac{1}{\sigma} \frac{\partial \sigma}{\partial H}$, Equation (25)

is solved for $\frac{1}{\sigma} \frac{\partial \sigma}{\partial (\log_e R_\theta)}$, Equation (26) is solved for $\frac{\partial \tilde{H}}{\partial H}$, Equation (27)

is solved for $\frac{\partial \tilde{H}}{\partial (\log_e R_\theta)}$, Equation (19) is solved for $\beta^{(e)}$, Equation (20)

is solved for $\hat{E}$, Equation (21) is solved for E, Equation (22) is solved

for H_ϕ, Equation (23) is solved for H_Δ, and Equations (28)-(31) are solved

for the derivatives of H_ϕ and H_Δ. Then, with superscript (t + 1) denoting

quantities at the first point downstream of transition, the following

equations are used to find Ω and ψ at that point:

$$\frac{\Omega^{(t+1)}}{L^2} = \frac{y^{(t+1)}}{L} \frac{\theta^{(t+1)}}{L} + \frac{H_\phi^{(t+1)}}{(\sec \alpha)^{(t+1)}} \left(\frac{\theta^{(t+1)}}{L} \right)^2 \tag{32}$$

and

$$\frac{\psi^{(t+1)}}{L^2} = \frac{y^{(t+1)}}{L} \tilde{H}^{(t+1)} \frac{\theta^{(t+1)}}{L} + \frac{1}{(\sec \alpha)^{(t+1)}} \left[\frac{(\tilde{H}^{(t+1)} + H^{(t+1)})^2}{2} \right.$$

$$\left. - H_\Delta^{(t+1)} \right] \left(\frac{\theta^{(t+1)}}{L} \right)^2 \tag{33}$$

At all points downstream of transition, Λ^* is found from

$$\frac{\Lambda^*}{L^2} = \frac{y}{L} H \frac{\theta}{L} + \frac{H_\Delta}{\sec \alpha} \left(\frac{\theta}{L} \right)^2 \tag{34}$$

At points downstream of the point immediately downstream of transition, Ω and ψ are found by integration of

$$\frac{d}{ds} \left(\frac{\Omega}{L^2} \right) = \frac{y}{L} \frac{\sec \alpha}{\sigma^2} - \frac{\Lambda^*/L^2 + 2 \Omega/L^2}{U/U_\infty} \frac{d}{ds} \left(\frac{U}{U_\infty} \right) \tag{35}$$

20

and

$$\frac{d}{ds}\left(\frac{\psi}{L^2}\right) = \left[\frac{Y}{L} + (\tilde{H} + H)\frac{\theta}{L}\right] E \sec \alpha - \frac{\psi/L^2}{U/U_\infty} \frac{d}{ds}\left(\frac{U}{U_\infty}\right) \tag{36}$$

Increments in $\frac{\theta}{L}$ and H are related to increments in $\frac{\Omega}{L^2}$ and $\frac{\psi}{L^2}$ through

the simultaneous difference equations

$$a_1 \Delta \left(\frac{\theta}{L}\right) + b_1 \Delta (H) = c_3 \tag{37}$$

and

$$a_2 \Delta \left(\frac{\theta}{L}\right) + b_2 \Delta (H) = c_4 \tag{38}$$

where $\Delta(z)$ represents the increment in z and

$$c_3 = \Delta \left(\frac{\Omega}{L^2}\right) - c_1 \tag{39}$$

$$c_4 = \Delta \left(\frac{\psi}{L^2}\right) - c_2 \tag{40}$$

$$a_1 = \frac{Y}{L} + \frac{1}{\sec \alpha} \frac{\theta}{L} \left[2 H_\phi + \frac{\partial H_\phi}{\partial (\log_e R_\theta)}\right] \tag{41}$$

$$b_1 = \frac{1}{\sec \alpha} \left(\frac{\theta}{L}\right)^2 \frac{\partial H_\phi}{\partial H} \tag{42}$$

$$c_1 = \frac{\theta}{L} \Delta \left(\frac{Y}{L}\right) + \left(\frac{\theta}{L}\right)^2 \left[H_\phi \Delta \left(\frac{1}{\sec \alpha}\right) - \frac{1}{\sec \alpha} \frac{\partial H_\phi}{\partial (\log_e R_\theta)} \frac{\Delta (U/U_\infty)}{U/U_\infty}\right] \tag{43}$$

21

$$a_2 = \frac{y}{L}\left[\tilde{H} + \frac{\partial \tilde{H}}{\partial (\log_e R_\theta)}\right] + \frac{1}{\sec \alpha}\frac{\theta}{L}\left[(\tilde{H} + H)^2 - \frac{H_\Delta}{2}\right.$$

$$\left. + (\tilde{H} + H)\frac{\partial \tilde{H}}{\partial (\log_e R_\theta)} - \frac{\partial H_\Delta}{\partial (\log_e R_\theta)}\right] \tag{44}$$

$$b_2 = \frac{y}{L}\frac{\theta}{L}\frac{\partial \tilde{H}}{\partial H} + \frac{1}{\sec \alpha}\left(\frac{\theta}{L}\right)^2\left[(\tilde{H} + H)\left(1 + \frac{\partial \tilde{H}}{\partial H}\right) - \frac{\partial H_\Delta}{\partial H}\right] \tag{45}$$

and

$$c_2 = \tilde{H}\frac{\theta}{L}\Delta\left(\frac{y}{L}\right) + \frac{y}{L}\frac{\theta}{L}\frac{\partial \tilde{H}}{\partial (\log_e R_\theta)}\frac{\Delta(U/U_\infty)}{U/U_\infty}$$

$$+ \left[\frac{(\tilde{H} + H)^2}{2} - H_\Delta\right]\left(\frac{\theta}{L}\right)^2\Delta\left(\frac{1}{\sec \alpha}\right)$$

$$+ \frac{1}{\sec \alpha}\left(\frac{\theta}{L}\right)^2\left[(\tilde{H} + H)\frac{\partial \tilde{H}}{\partial (\log_e R_\theta)}\right.$$

$$\left. - \frac{\partial H_\Delta}{\partial (\log_e R_\theta)}\right]\frac{\Delta(U/U_\infty)}{U/U_\infty} \tag{46}$$

Equations (35)-(38) enable $\frac{\Omega}{L^2}$, $\frac{\psi}{L^2}$, $\frac{\theta}{L}$, and H to be found at the (i - th + 1) point in terms of functions evaluated at the i-th point The values at the (i - th + 1) point enable Equations (16)-(31) and Equation (34) to be used to evaluate the remaining functions, so that the process can be continued to the end of the body.

CALCULATION OF DRAG

Equation (7) in Granville[1] gives the formula for drag coefficient based on a reference area A as

$$C_D = 4\pi\frac{\Omega^{(D)}/L^2}{A/L^2} \tag{47}$$

where $\Omega^{(D)}$ is the momentum area of the wake far downstream. This equation is the result of considering the momentum balance of a flow through a control volume which contains the body and has dimensions sufficiently large that the pressure at all points on its surface is effectively equal to the pressure in the undisturbed flow.

If the superscript (e) denotes values at the tail of the body, $\Omega^{(D)}$ can be found from Equation (95) in Granville[1] (with q = 7, as suggested) as

$$\frac{\Omega^{(D)}}{L^2} = \frac{\Omega^{(e)}}{L^2} \left(\frac{U^{(e)}}{U}\right)^{\frac{7h^{(e)}+17}{8}} \tag{48}$$

where h is the axisymmetric shape parameter defined by

$$h = \Lambda^{\star}/\Omega \tag{49}$$

Therefore $h^{(e)}$ is given by

$$h^{(e)} = \frac{\Lambda^{\star (e)}/L^2}{\Omega^{(e)}/L^2} \tag{50}$$

COMPARISON OF PREDICTED AND MEASURED DRAG COEFFICIENTS AND TRANSITION POINTS

Data on bodies of revolution with and without parallel middlebodies are available from recent experiments. The body without parallel middlebody is represented by the DOLPHIN, for which measurements were made during drop tests in the Pacific Ocean.[14,15] Data on three bodies of revolution with parallel middlebodies are available from recent DTNSRDC

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[14] Carmichael, B. H., "Underwater Drag Reduction through Choice of Shape," American Institute of Aeronautics and Astronautics Paper 66-657 (1966).

[15] Carmichael, B. H., "Underwater Drag Reduction through Optimum Shape," in "Underwater Missile Propulsion," edited by Leonard Greiner, Compass Publications, Arlington, Virginia (1967), pp. 147-169.

towing-tank tests of Models 4620-2, 4620-3, and 4620-4. The speed range of the towing-tank experiments included the range where the length Froude number is between 0.5 and 0.6, in which the theoretical maximum of the wave-drag coefficients of submerged streamlined bodies of revolution occur. No attempt has been made to correct for wave drag, but this Froude-number range is indicated on figures which show the results of the towing-tank experiments. In all of these figures, the Schoenherr friction line for a flat plate with turbulent boundary layer is drawn in for reference since the calculation method reproduces this line if the pressure gradient is set equal to zero, the body radius is set equal to a sufficiently large constant, and transition is forced at the nose.

In this section, C_D is the drag coefficient based on wetted area, x_t is the axial distance from the nose to the transition point, L is the model length, and R_L and F_L are the Reynolds number and Froude number based on L and model speed.

DOLPHIN

The DOLPHIN profile is that of an NACA 66-030 airfoil section, faired into a boom at the stern on which stabilizing fins are mounted. Drop tests were performed in the Pacific Ocean and speed was computed from a time history of the dynamic pressure at the model nose. The reported drag is for the "airfoil" portion of the model only; the boom and fin drag were estimated by a method described by Carmichael[14,15] and subtracted out. Consequently the drag coefficients reported here are for a model truncated at the stern of the airfoil profile. The actual DOLPHIN and the truncated approximation are shown in Figure 4. The offsets of the approximation are listed in Table 1.

Figure 5 shows the predicted drag coefficients and transition points, the "measured" drag coefficients, and transition points deduced from the measured drag coefficients according to the method of Young.[16] Considerable scatter among the results is apparent; this might be

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[16]Young, A. D., "The Calculation of the Total and Skin Friction Drags of Bodies of Revolution at Zero Incidence," British Aeronautical Research Committee Reports and Memoranda 1874 (Apr 1939).
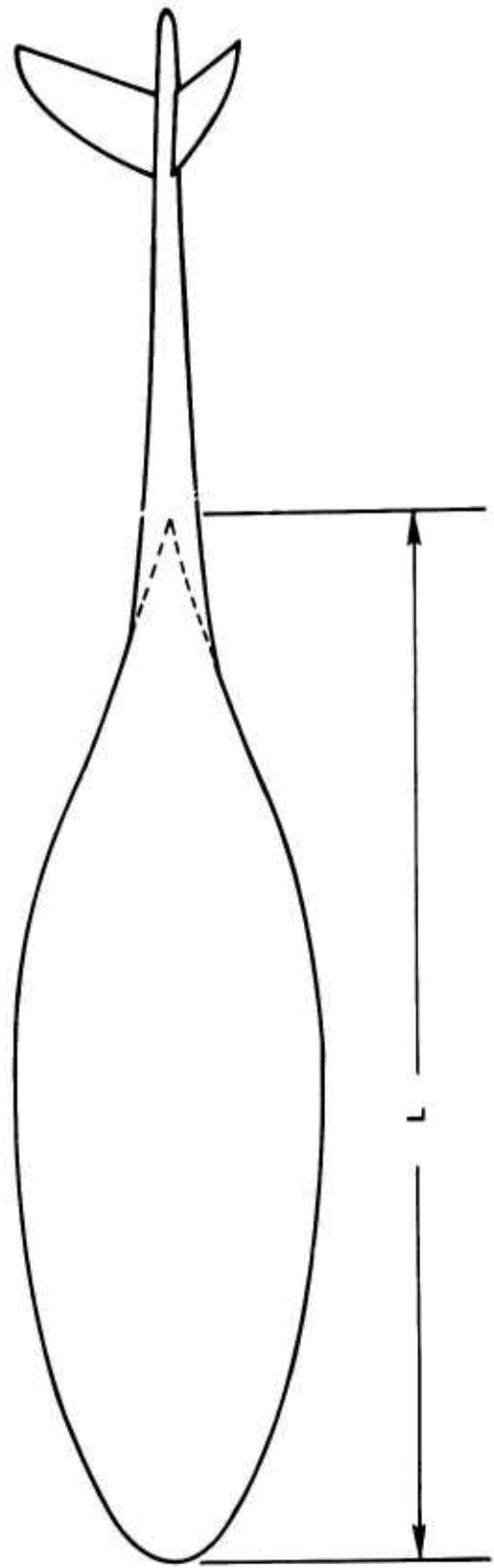
Figure 4 – Shapes of Actual and Approximated DOLPHIN
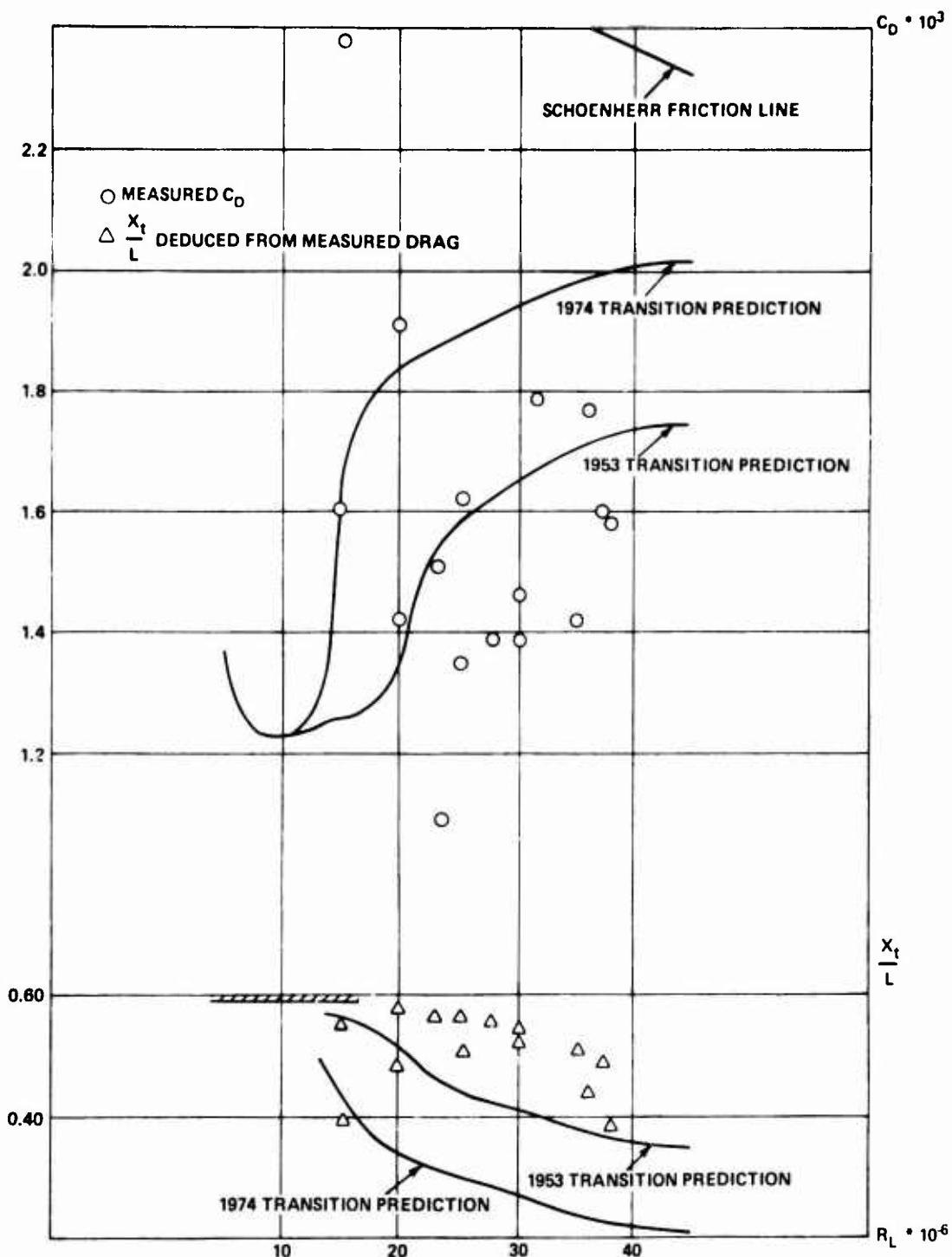
Figure 5 – Predicted and Measured C_D and $\dfrac{x_t}{L}$ for DOLPHIN

TABLE 1 - OFFETS AND DIMENSIONS OF APPROXIMATED DOLPHIN

$\frac{X}{L}$	$\frac{Y}{L}$	$\frac{X}{L}$	$\frac{Y}{L}$
0.00	0.00000	0.35	0.14565
0.01	0.02768	0.40	0.14894
0.02	0.03920	0.45	0.15000
0.03	0.04808	0.50	0.14874
0.04	0.05556	0.55	0.14434
0.05	0.06215	0.60	0.13635
0.06	0.06810	0.65	0.12478
0.07	0.07354	0.70	0.10992
0.08	0.07859	0.75	0.09228
0.09	0.08329	0.80	0.07262
0.10	0.08770	0.85	0.05187
0.15	0.10635	0.90	0.03133
0.20	0.12072	0.95	0.01287
0.25	0.13178	1.00	0.00000
0.30	0.14000		

Total Length, ft	6.300
Wetted Area, ft^2	18.150
Volume, ft^3	5.600

attributed to variations in the ocean ambient-turbulence levels between tests since such variations are believed to affect the mechanism of boundary-layer transition. Nonetheless, the lines representing drag coefficients and transition points based on the 1953 prediction of transition are seen to lie closer to the measured drag coefficients and deduced transition points than do the lines of the 1974 transition prediction.

MODELS 4620-2, 4620-3, AND 4620-4

These models have streamlined forebodies and afterbodies separated by parallel middlebodies. Note from the model offsets (Table 2) that Model 4620-2 has the bluntest nose of the three and that Model 4620-4 has the finest nose. The models were towed by vertical struts extending down from the towing carriage into the tops of the models near amidships. Each model was tested in a bare-hull condition and with an 0.024-inch

TABLE 2 - OFFSETS AND DIMENSIONS OF MODELS 4620-2, 4620-3, AND 4620-4

$\frac{X}{L}$	$\frac{Y}{L}$, 4620-2	$\frac{Y}{L}$, 4620-3	$\frac{Y}{L}$, 4620-4
0.00	0.00000	0.00000	0.00000
0.01	0.01954	0.01431	0.01096
0.02	0.02753	0.02023	0.01549
0.03	0.03339	0.02472	0.01897
0.04	0.03789	0.02845	0.02188
0.05	0.04127	0.03163	0.02443
0.06	0.04363	0.03437	0.02670
0.07	0.04507	0.03674	0.02875
0.08	0.04573	0.03876	0.03062
0.09	↑	0.04045	0.03233
0.10		0.04183	0.03388
0.15		0.04472	0.03967
0.20	P.M.B.		0.04254
0.25	from	↑	0.04322
0.30	x/ℓ 0.088		↑
0.35	to	P.M.B.	
0.40	x/ℓ 0.60	from	P.M.B.
0.45	with	x/ℓ 0.16	from
0.50	y/ℓ 0.04587	to	x/ℓ = 0.26
0.55		x/ℓ 0.61	to
0.60	↓	with	x/ℓ - 0.62
0.60	0.04587	y/ℓ = 0.04475	with
0.65	0.04543		y/ℓ = 0.04323
0.65		0.04449	↓
0.70	0.04345	0.04280	0.04312
0.70			0.04182
0.75	0.03986	0.03942	0.03874
0.80	0.03502	0.03471	0.03421
0.85	0.02915	0.02892	0.02856
0.90	0.02260	0.02186	0.02164
0.95	0.01273	0.01268	0.01261
1.00	0.00000	0.00000	0.00000

Models	4620-2	4620-3	4620-4
Total Length, ft	22.300	22.859	23.664
Wetted Area, ft^2	123.871	124.764	126.345
Volume, ft^3	58.102	58.102	58.102

wire ring mounted at 5 percent of the axial distance aft of the nose to stimulate boundary-layer transition at that station. In the presentation of the drag coefficients measured in these experiments, no attempt has been made to estimate the drag on the wire ring and subtract it out.

The experiments conducted with these models are described in detail by McCarthy, Power, and Huang.[17]

The drag-coefficient results of Model 4620-2 are shown in Figure 6. This model is so blunt that the laminar-separation point was only 8.1 percent of the axial length aft of the nose; both methods predict that transition in the bare-hull experiments will take place there throughout the speed range used. It is seen that below the Reynolds-number range where there is appreciable wavemaking drag, the drag prediction is fairly good; the overprediction is generally no more than 3 percent for both artificially tripped transition and transition which takes place at the laminar-separation point. However, the overprediction in the former case is actually larger because trip-wire drag is included in the measurements.

The drag coefficients and transition points for Model 4620-3 are shown in Figure 7. The 1953 transition-point prediction method is accurate except at the lower Reynolds numbers, where both methods predict transition much further back on the parallel middlebody than the point at which it was measured.* At Reynolds numbers where transition occurred on the forebody, the 1953 method predicted its location to within about 6 percent; the 1974 method predicted it slightly further aft. In the Reynolds-number range between about 12 and 22 million (for which the 1953 method predicted the transition point to this accuracy and wavemaking drag was negligible) the drag coefficient predicted by using the 1953 method is quite accurate; it overpredicts the drag by less than 2 percent. However, drag overprediction is larger with tripped transition; 5 percent is representative. Again, this is actually larger because the measured drag includes the drag of the trip wire.

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[17] McCarthy, J. H. et al., "The Roles of Transition, Laminar Separation, and Turbulence Stimulation in the Analysis of Axisymmetric Body Drag," DTNSRDC Report 4728 (in review).

*The Granville 1974 correlation[2] does not include bodies with parallel middlebodies and hence is not strictly applicable here.
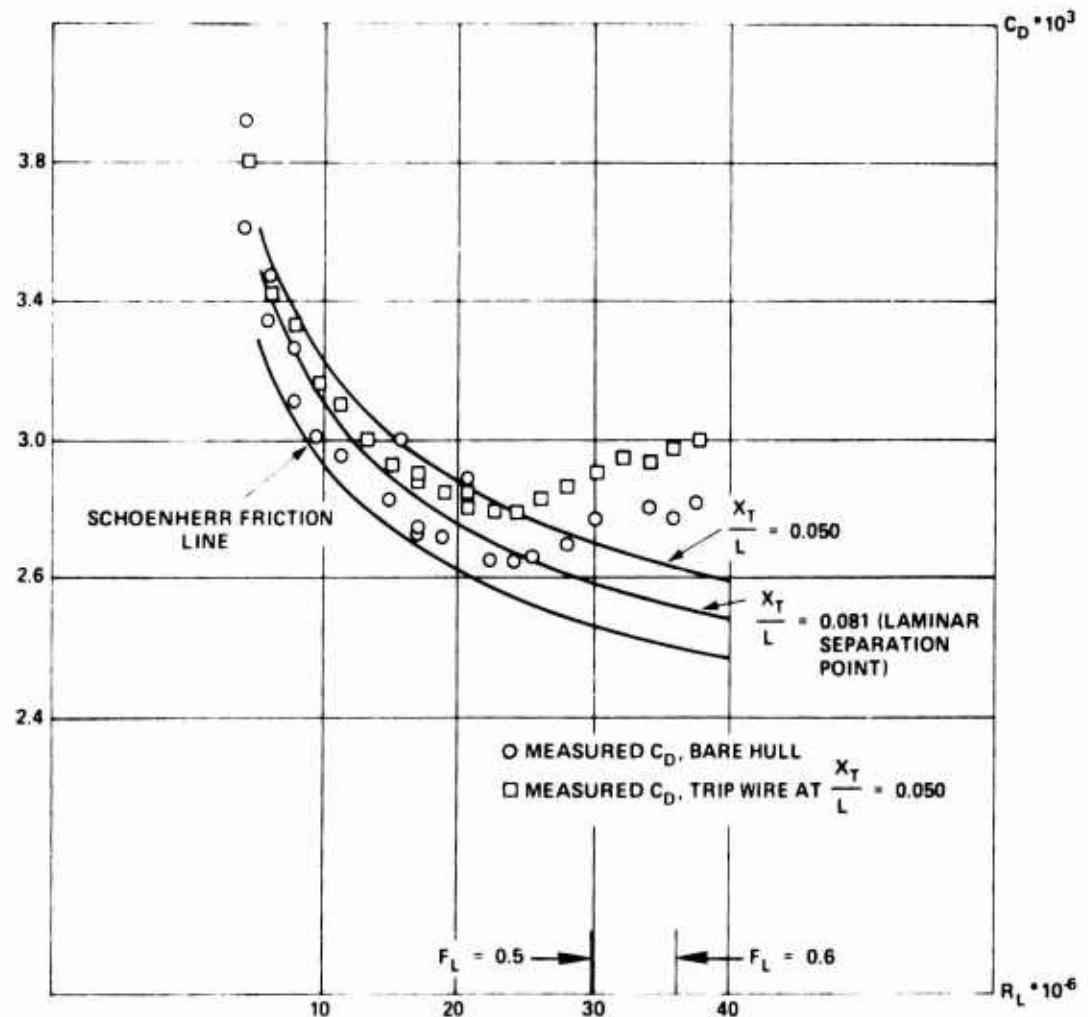
Figure 6 – Predicted and Measured C_D for Model 4620-2
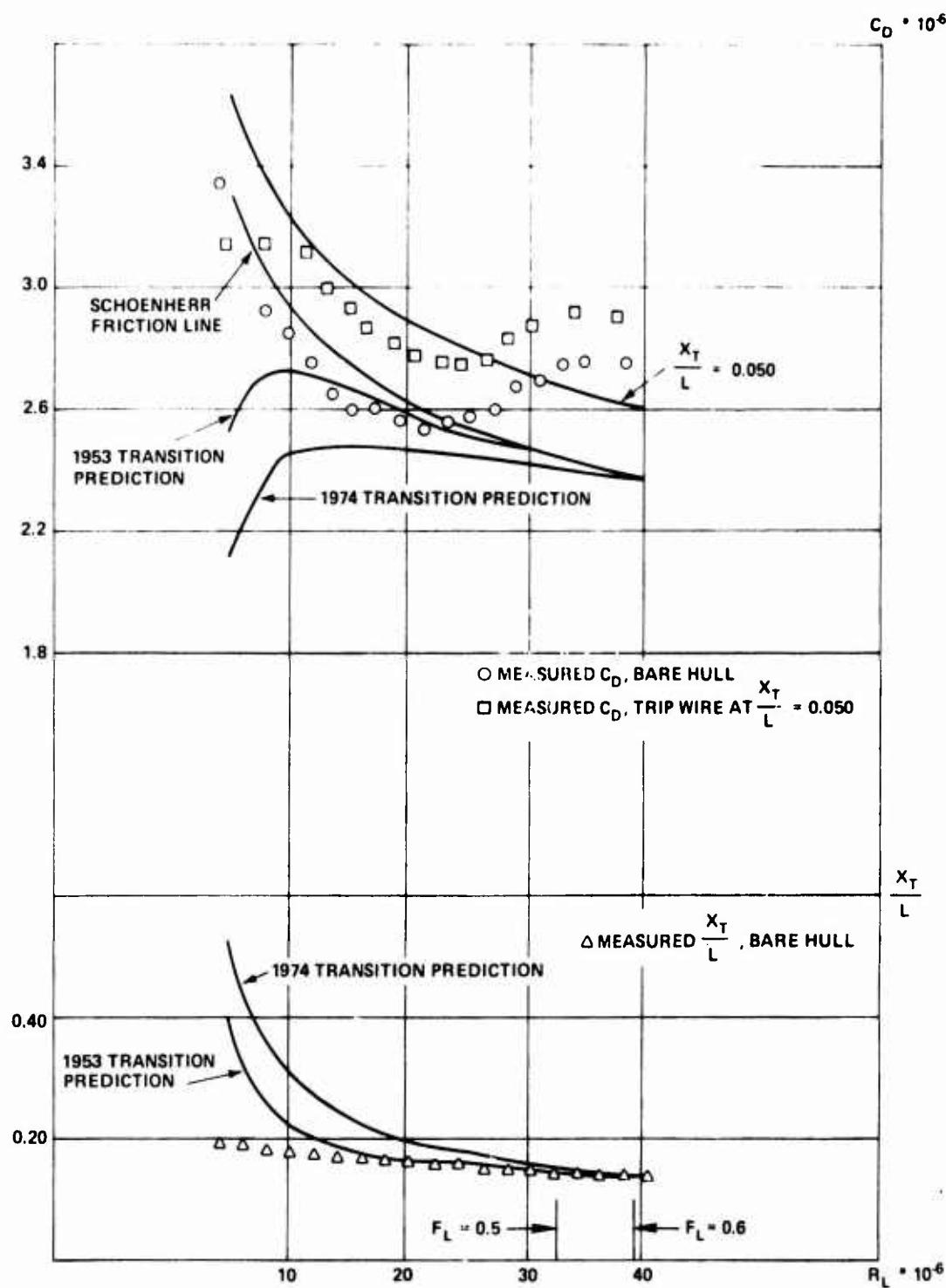
Figure 7 – Predicted and Measured C_D and $\frac{x_t}{L}$ for Model 4620-3

Figure 8 shows the results for Model 4620-4. The 1953 method predicted the transition point to within 7 percent in the Reynolds-number range between about 10 and 17 million; at higher Reynolds numbers, the 1974 method was the more accurate, predicting it to within 10 percent; below this range, both methods predicted transition much further aft of where it was measured. In the Reynolds-number range between about 10 and 20 million, where the 1953 method is fairly accurate, the drag coefficient is predicted to within 3 percent. The 1974 method predicted the transition point more accurately at Reynolds numbers above this range; it also predicted the drag coefficient to within 3 percent at Reynolds numbers between 20 and 25 million, above which wavemaking drag becomes appreciable. The drag coefficient with tripped transition is overpredicted; once more, the discrepancy is actually greater than it appears because trip-wire drag is included in measured drag.

DISCUSSION AND CONCLUSIONS

The most important conclusion to be drawn from the foregoing is that the updated turbulent-boundary-layer theory of Granville[4] is capable of giving reasonable predictions of the viscous drag on streamlined bodies of revolution as long as the transition point is located accurately. The digital-computer program makes it possible to use the theory on a routine basis; no numerical difficulties have arisen. In cases where the transition point is fixed by tripping the laminar boundary layer or where the transition point is predicted accurately, comparison with measured drag shows the theory and computer program consistently overpredict the drag coefficient by as much as 5 percent. This may be due to the values of the boundary-layer constants used which have considerable experimental variation.

Unfortunately, two factors which have been neglected would each increase the overprediction had they been considered. First, the additional drag due to the presence of displacement thickness is not present in the predictions since, in the cases presented here, the drag calculations were not repeated after the appropriate modification to the hydrodynamic source strength. Second, in cases where the trip wire was
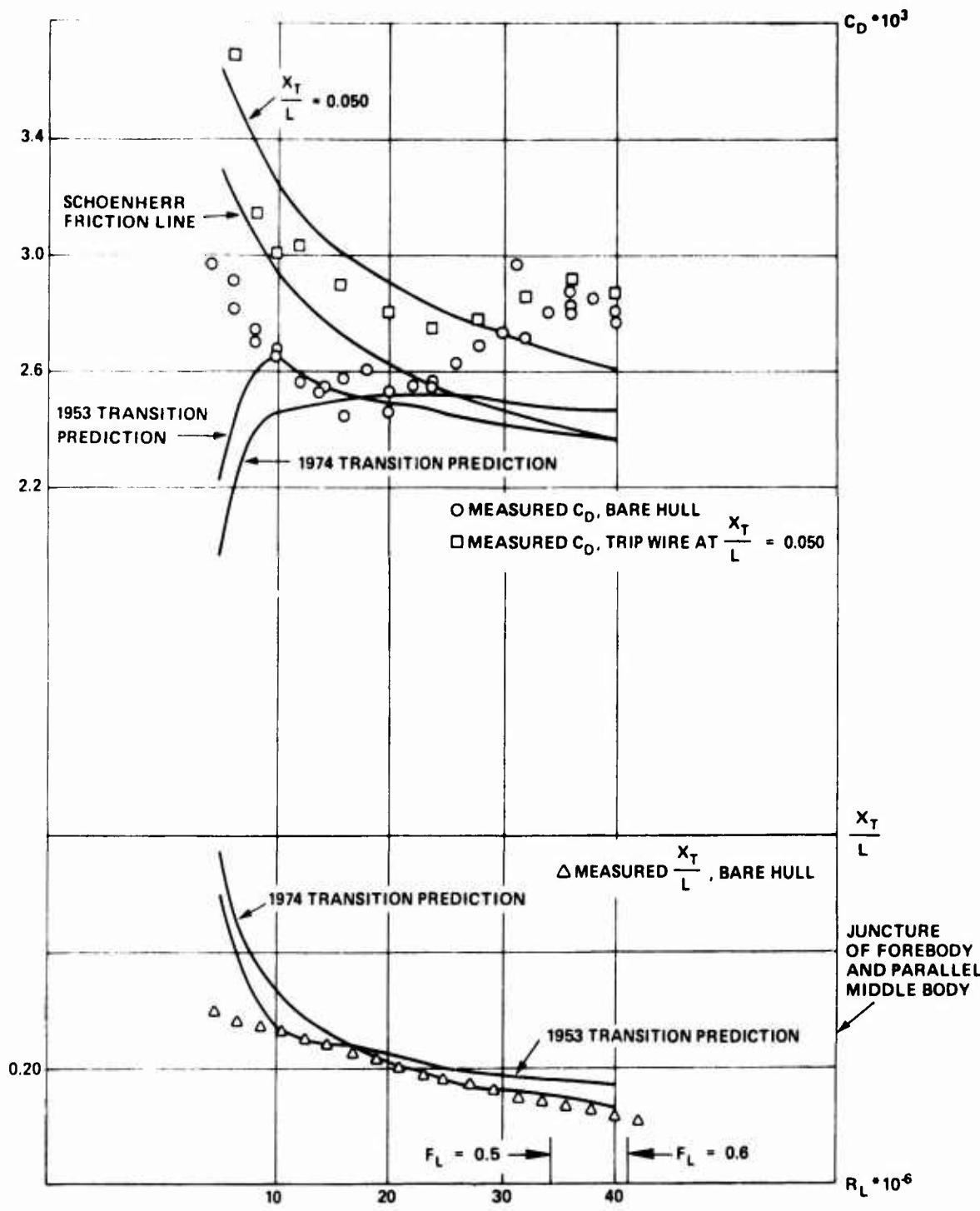
Figure 8 — Predicted and Measured C_D and $\frac{x_t}{L}$ for Model 4620-4

33

mounted, the measured drag includes the drag on the wire and thus is artificially increased. Furthermore, the overprediction was present (and often at its worst) when transition was fixed at only 5 percent aft of the nose. Thus it cannot be attributed to an inaccuracy in the laminar-boundary-layer calculations. As was mentioned, the program reproduces the Schoenherr frictional line for a flat plate with turbulent boundary layer under the appropriate circumstances. Therefore, the overprediction should be attributed to the means by which the presence of a pressure gradient is included in the turbulent-boundary-layer calculations, either on the body itself or in the turbulent wake since the drag calculation is based on a particular model of the wake.

A better means of estimating the location of the transition point is needed since, at Reynolds numbers of 10 million or less, an inaccurate prediction of the transition point results in a serious error in the drag prediction; see Figures 7 and 8. Comparison between the two transition-point prediction methods is inconclusive. Figures 7 and 8 show that neither is accurate if transition occurs on the parallel middlebody, although the 1974 method is not intended for this case. Aside from this, Figures 5, 7, and 8 show that the 1953 method was more accurate for DOLPHIN, Model 4620-3, and the lower part of the Reynolds-number range for Model 4620-4, whereas the 1974 method was more accurate in the upper part of the Reynolds-number range for Model 4620-4.

Comparison of the location of the Schoenherr friction line for a flat-plate turbulent boundary layer relative to the measured drag coefficients in Figure 5 with its same relative location in Figures 6, 7, and 8 shows that the designers of DOLPHIN were successful in selecting a body of revolution which maintained an appreciable extent of laminar boundary layer throughout a practical range of Reynolds numbers.

ACKNOWLEDGMENTS

34

of the McDonnell-Douglas Corporation and Charles W. Dawson and Janet S. Dean of the Computation and Mathematics Department at DTNSRDC assisted in matters relating to the modification and use of the Douglas-Neumann potential-flow program. Bruce H. Carmichael of the Rockwell International Corporation provided descriptions of the DOLPHIN design and experiments.

APPENDIX A

DESCRIPTION, GLOSSARY, LISTING, AND SAMPLE
RUN OF DPIN1

DESCRIPTION OF DPIN1

This program uses the method of Granville[18] to compute the offsets
and slopes of a streamlined body of revolution formed by a forebody with
rounded nose, no parallel middlebody, and an afterbody with pointed
tail. The axis of symmetry is the x-axis, the nose is at the origin,
and the tail is at x = 1.0. On the forebody, y is equal to the square
root of a quartic in x; on the afterbody, it is equal to the square root
of a quintic. Coefficients in the quartic and quintic are specified by
geometric parameters which are input variables together with the require-
ment that the slope dy/dx be zero and that the curvature d^2y/dx^2 be
continuous at the forebody-afterbody juncture, which is the location of
maximum diameter.

As calculated by this program, the bodies are represented by series
of frustums of cones with generating axis along the axis of revolution
since the body shapes are formed by straight-line segments between
points defined by pairs of x- and y- coordinates. One feature of the
program is that the segment lengths of step sizes over the foremost
portion of the body are one-tenth as large as those over the rest of it.
(A different ratio of step sizes could be attained by a minor modifica-
tion to the appropriate DPIN and to DPOUT.) The change from the smaller
to the larger step size is made over a total of three steps in such a
way that no step is more than twice as large as the one preceding it.
Experience in operation of the axisymmetric potential-flow program has
shown the desirability of this relatively gradual change.

Input variables to the program consist of the integers NPTS, NCPTS,
and INFL and the floating-point numbers M, KL, RL, SL, and ELD. NPTS
and NCPTS are the total number of points on the body and the number of
closely spaced points. INFL is the maximum number of inflection points

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[18]Granville, P. S., "Geometrical Characteristics of Streamlined Shapes,"
NSRDC Report 2962 (Mar 1969); also Journal of Ship Research, Vol. 13,
No. 4, pp. 299-313 (Dec 1969).

permitted on the afterbody; it must be either 0 or 1. M is the ratio of
the forebody length to total length, KL is the curvature at maximum
diameter, RL is the radius of curvature at the nose, SL is the slope at
the tail, and ELD is the ratio of total length to maximum diameter. KL,
RL, and SL are expressed in coordinates scaled so that the total length
of the body is 1.

In order to use the Granville[18] polynomials, they are transformed
to a stretched coordinate in which the forebody or afterbody length and
the maximum radius each equals 1. Thus the coefficients in the quartic
for the forebody are R, the stretched nose radius, and KF, the stretched
curvature at maximum diameter. The coefficients in the quintic for the
afterbody are KA, the (differently) stretched curvature at maximum diam-
eter, and S2, the square of SP, the stretched slope at the tail. KF,
KA, and SP also have their signs reversed so as to be ordinarily posi-
tive. The Granville[18] method of avoiding undesirable bulges, zeros, and
inflection points on the forebody requires R and KF to lie in an admiss-
ible region when graphed (see Figures 2-4 of Reference 18, in which they
are denoted by r and k_1). In the same way, undesirable afterbodies are
excluded by requiring that S2 and KA lie in one of two admissible regions
when graphed (see Figures 6 and 7 of Reference 18, in which they are
denoted by s^2 and k_1), according to whether zero or one inflection
points are to be allowed on the afterbody.

Instead of introducing the complications associated with numerical
representation of the curves which delineate the admissible regions on
the graphs, DPIN1 uses a different method for checking the occurrence of
bulges and points of inflection: as the slope at each point is computed,
it is compared with zero and the slope at the previous point. If at
points on the forebody the slope is negative or greater than the previous
slope, the program prints out a message that the forebody parameters are
inadmissible and stops. At points on the afterbody, the program prints
out the corresponding message and stops if the slope is positive or, if
no inflection points are permitted (INFL = 0), the slope is greater than
the previous slope. If one inflection point is permitted (INFL = 1),

38

the slope is allowed to exceed the previous slope over a range of points, past which it may become less than the previous slope over one range but must not exceed the previous slope over a second range.

The program user may wish to modify DPIN1 so that KF, KA, R, and S2 (or its square root) are used as input rather than the unstretched KL, RL, and SL. Furthermore, he may wish to replace either KF or R with CPF, the forebody prismatic coefficient, or to replace either KA or S2 with CPA, the afterbody prismatic coefficient, since Equations (265) and (266) in Granville[18] present linear relations between these respective triads of geometric parameters.

After DPIN1 has read its seven input variables, it writes them out. Next it computes the stretched variables and the forebody, afterbody, and overall prismatic coefficients and writes them out. Then it finds the appropriate step size DX and proceeds to calculate the offsets Y(I) at each point along the forebody and afterbody by taking the square root of the appropriate polynomial. The slope DYDX(I) and increment in arc length DS are calculated by using the derivative of the polynomial. The wetted area and a geometric function TP(I), which is used for predicting boundary-layer transition, are also computed at each point. Then I, X, Y, DYDX, S, and TP are written out for each point. Finally the total volume, forebody and afterbody lengths, and the forebody, afterbody, and overall wetted areas and arc lengths are written out. X(I), Y(I), DYDX(I), and the volume, wetted area, length-to-diameter ratio, and numbers of points and of close points are also written on tape for use by subsequent programs.

DPIN1 - GLOSSARY

The following glossary of variables used in DPIN1 is arranged alphabetically by FORTRAN variable name.

39

FORTRAN Variable Name	Variable	Definition
AA	$A^{(a)}/L^2$	Wetted area of afterbody divided by length squared
AF	$A^{(f)}/L^2$	Wetted area of forebody divided by length squared
AT	$A^{(t)}/L^2$	Total wetted area divided by length squared
CP	C_p	Prismatic coefficient of complete body
CPA	$C_p^{(a)}$	Prismatic coefficient of afterbody
CPF	$C_p^{(f)}$	Prismatic coefficient of forebody
DS	ds/L	Increment in arc length s divided by total length
DX	dx/L	Increment in axial length x divided by total length
DYDX	$\dfrac{dy}{dx}$	Slope, dimensioned to be a function of I
ELD	L/MAX. DIAMETER	Ratio of total length to maximum diameter
I	i	Integer which increases from 1 at the nose to NCPTS at the point where step size begins increasing, thence to NPTS at the tail
INFL		Control variable which specifies the maximum number of inflection points allowed on the afterbody; always input as 0 or 1
KA	$k_1^{(a)}$	Curvature at forebody-afterbody juncture, normalized for unit afterbody length and unit maximum radius, with sign reversed so as to be ordinarily positive

FORTRAN Variable Name	Variable	Definition
KF	$k_\ell^{(f)}$	Curvature at forebody-afterbody juncture, normalized for unit forebody length and unit maximum radius, with sign reversed so as to be ordinarily positive
KL	$L \left.\dfrac{d^2 y}{dx^2}\right|_{\substack{\text{(forebody-}\\ \text{afterbody}\\ \text{juncture)}}}$	Total length times curvature at forebody-afterbody juncture
M	m	Ratio of forebody length to total length
M1	$1 - m$	Ratio of afterbody length to total length
NCPTS	$n^{(c)}$	Number of the point downstream of which the point spacing begins to increase
NC1	$n^{(c)} + 1$	
NC2	$n^{(c)} + 2$	
NC3	$n^{(c)} + 3$	
NC4	$n^{(c)} + 4$	
NPTS	n	Total number of points
PI	π	Ratio of the circumference of a circle to its diameter
R	r	Radius of curvature at nose, normalized for unit forebody length and unit maximum radius
RL	$\dfrac{1}{L} \left.\dfrac{d^2 x}{dy^2}\right|_{\text{(nose)}}$	Radius of curvature at nose, divided by total length
S	s/L	Arc length at arbitrary x, divided by total length; dimensioned to be a function of I

FORTRAN Variable Name	Variable	Definition
SA	$s^{(a)}/L$	Arc length of afterbody divided by total length
SF	$s^{(f)}/L$	Arc length of forebody divided by total length
SL	$\left.\dfrac{dy}{dx}\right\|_{(tail)}$	Slope at tail
SP	$s^{(p)}$	Slope at tail, normalized by unit afterbody length and unit maximum radius, with sign reversed so as to be ordinarily positive
ST	$s^{(t)}/L$	Total arc length divided by total length
S2	$s^{(p)^2}$	SP squared
TP	$\dfrac{1}{ELD\ y(x)}\dfrac{dy}{dx}$	Function used in DPOUT to predict transition; dimensioned to be a function of I
VL3	V/L^3	Volume of body divided by cube of total length
X	x/L	Axial coordinate divided by body length; dimensioned to be a function of I
XA	$\dfrac{1-x/L}{1-m}$	Reversed x, normalized to increase from XA = 0 at the tail to XA = 1 at the forebody-afterbody juncture
XA1	$\dfrac{m-x/L}{1-m}$	Reversed x, normalized to increase from XA1 = -1 at the tail to XA1 = 0 at the forebody-afterbody juncture
XF	x/Lm	x normalized to increase from XF = 0 at the nose to XF = 1 at the forebody-afterbody juncture

FORTRAN Variable Name	Variable	Definition
XF1	$\dfrac{x/L - m}{m}$	x normalized to increase from XF1 = -1 at the nose to XF1 = 0 at the forebody-afterbody juncture
XX	x/L	Axial length, identical to x except that it is not dimensioned as a function of I
Y	y/L	Body radius divided by total length; dimensioned to be a function of I

LISTING AND SAMPLE OUTPUT OF DPIN1

```
      PROGRAMDPIN1(INPUT,OUTPUT,TAPE60,TAPE61,TAPE5=INPUT,TAPE6=OUTPUT,TA
     UAPE86)
      DIMENSION X(202),Y(202),DYDX(202),S(202),TP(202)
      REAL M, M1, KL, KF, KA
C     THIS PROGRAM COMPUTES THE OFFSETS, SLOPES, AREAS, AND VOLUMES
C     OF A BODY FORMED BY POLYNOMIAL NOSE AND TAIL, ACCORDING TO
C     GRANVILLE, NSRDC REPORT 2962, 1969
      READ(5,16) NPTS,NCPTS,INFL
   16 FORMAT(3I10)
      WRITE(6,17) NPTS,NCPTS,INFL
   17 FORMAT(1X,*NPTS=*,I5,3X,*NCPTS=*,I5, 3X, *INFL = *,I5)
    7 READ(5,1) M,KL, RL, SL, ELD
      IF(EOF(5))8,9
    1 FORMAT(5F10.6)
    9 WRITE(6,5) M, KL, RL, SL, ELD
    5 FORMAT(1H1,10X*INPUT*//* M=*F10.6*  KL  =*F10.6* RL  = *, F10.6
     1,* SL   =*F10.6* ELD =*F10.6)
      M1 = 1.-M
      KF =-2.*M*M*ELD*KL
      KA =-2.*M1*M1*ELD*KL
      R = 4.*M*ELD*ELD*RL
      SF =-2.*ELD*M1*SL
      S2 = SP*SP
      WRITE(6,10)
   10 FORMAT(///10X*OUTPUT*//)
      WRITE(6,4) R, KF, KA, S2
    4 FORMAT(/* R =*F12.5*  KF=*F12.5*  KA=*F12.5*  S2=*F12.5)
      WRITE (6,22)
   22 FORMAT (/1X,* CPF IS PRISMATIC COEFFICIENT OF FOREBODY. CPA IS
     +PRISMATIC COEFFICIENT OF AFTERBODY.  CP IS OVERALL PRISMATIC
     +COEFFICIENT*)
      CPF = .1*R -KF/30. + .6
      CPA = (S2-KA)/60.+.5
      CP = M*CPF+M1*CPA
      WRITE (6,23) CPF,CPA, CP
```

44

```
23 FORMAT (/1X,* CPF =*,F11.8,3X, *CFA = *,F11.8,3X, *CP = *, F11.8)
   WRITE (6,18)
18 FORMAT (//4X, *I*, 9X,*X*, 1*X, *Y*, 14X, *DYDX*, 11X, *S*, 14X,
  +*TP*/)
   DX=.001       $X(1)=0.      $Y(1)=.       $PI=3.14159   $S(1)=0. $AF=0. $AA=0.
   DYDX(1) = 10.*100.*1000.
   TP(1) = 10.*100.*1000.
   NC1=NCPTS+1   $NC2=NCPTS+2  $NC3=NCPTS+3  $NC4=NCPTS+4
   DO 2 I=2,NPTS
   IF(I.EQ.NC1) DX = .002
   IF(I .EQ. NC2) DX = .003
   IF(I .EQ. NC3) DX = .005
   IF(I .EQ. NC4) DX = .010
   X(I)=X(I-1)+DX       $XX=X(I)
   IF(XX.GE. 4)GOTO3
   XF = XX/M     $XF1 = (XX-M)/M
   Y(I) = SQRT(-R*2.*XF*XF1**3-KF*XF*XF*XF1*XF1*XF*XF*(3.*XF*XF
  +-8.*XF+6.))/(2.*ELD)
   DYDX(I) = (-R*2.*XF1*XF1*(XF1+(XF1+3.*XF)-2.*KF*XF*XF1*(XF1+XF)
  ++XF*(2.*(3.*XF*XF-8.*XF+6.)+XF*(6.*XF-8.))/(8.*ELD*Y(I)*M)
   IF ((DYDX(I).GT.DYDX(I-1)).OR.(DYDX(I).LT.-.000000000009)) GO TO 11
   DS = DX*SQRT(1.+DYDX(I)*DYDX(I))
   IF (I.NE.2) GO TO 19
   S(2) = SQRT((X(2)-X(1))*(X(2)-X(1))+(Y(2)-Y(1))*(Y(2)-Y(1)))
   GO TO 27
19 CONTINUE
   S(I) = S(I-1) + DS   $TP(I)=DYDX(I)/(Y(I)*ELD)
27 CONTINUE
   SF = S(I)
   AF = AF+2.*PI*Y(I)*DS
   XA=(1.-XX)/M1        $XA1=(M-XX)/M1
   Y(I) = SQRT(-S2*XA*XA*XA1**3-KA*XA*XA1*XA1*XA**3*(6.*XA*XA
  +-15.*XA+10.))/(2.*ELD)
   DYDX(I) = (-S2*XA*XA1*XA1*(2.*XA1+3.*XA)-KA*XA*XA1*(3.*XA1
  ++2.*XA)*XA*XA*(3.*(6.*XA*XA-15.*XA+10.)+XA*(12.*XA-15.))/(6.*ELD
  ++ELD*Y(I)*(-M1))
   IF (DYDX(I).GT.0.) GO TO 12
3
```

```
      IF (INFL.NE.0) GO TO 28
      IF (DYDX(I).GT.DYDX(I-1)) GO TO 12
      GO TO 29
28    CONTINUE
      IF((DYDX(I).GT.DYDX(I-1)).AND.(INFL.EQ.1)) INFL = 2
      IF((DYDX(I).LT.DYDX(I-1)).AND.(INFL.EQ.2)) INFL = 3
      IF((DYDX(I).GT.DYDX(I-1)).AND.(INFL.EQ.3)) GO TO 12
29    CONTINUE
      DS = DX*SQRT(1.+DYDX(I)*DYDX(I))
      S(I) = S(I-1) + DS  $TP(I)=DYDX(I)/(Y(I)*ELD) $AA=AA+2.*PI*Y(I)*DS
      SA = S(I)-SF
2     CONTINUE
6     WRITE(6,6) ( I, X(I), Y(I), DYDX(I),S(I),TP(I),I=1,NPTS)
6     FORMAT(2X, I3, 5F15.5)
      WRITE(60)(X(I),Y(I),I=1,NPTS)
      ENDFILE 60
      WRITE(61)(DYDX(I),I=1,NPTS)
      VL3 = .25*PI*CF/(ELD*ELD)
      WRITE(6,15) VL3
15    FORMAT(/1X,* VOLUME/L3  = *,F15.7/)
      WRITE (6,20)
20    FORMAT (/1X, * L IS OVERALL LENGTH.  LF IS LENGTH OF FOREBODY.  LA
     * IS LENGTH OF AFTERBODY.*)
      WRITE (6,21) L, M1
21    FORMAT (/1X,* LF/L =*,F12.5,*    LA/L =  *,F12.5)
      WRITE (6,24)
      AT = AF+AA
24    FORMAT(/1X,* AREAF IS SURFACE AREA OF FOREBODY. AREAA IS SURFACE
     +AREA OF AFTERBODY. AREAT IS TOTAL SURFACE AREA.*)
      WRITE (6,25)       AF,AA, AT
25    FORMAT(/1X,* AREAF/L2  = *,F11.8,* AREAA/L2  = *,F11.8,
     +* AREAT/L2  = *,F11.8)
      ST = SF+SA
      WRITE (6,26) SF, SA, ST
26    FORMAT(/, 1X, *FOREBODY ARC LENGTH/L = *,F10.6, 3X, *AFTERBODY
     +ARC LENGTH/L = *,F10.6,3X, * TOTAL ARC LEGNTH/L = *, F10.6)
      WRITE (88) VL3,AT, ELD, NPTS, NCPTS
```

46

```
       GOTO7
11     WRITE(6,13) $STOP
13     FORMAT(//* FOREBODY PARAMETERS ARE INADMISSIBLE*)
12     WRITE(6,14) $STOP
8      CONTINUE
14     FORMAT(//* AFTERBODY PARAMETERS ARE INADMISSIBLE*)
       END
```

INPUT

NPTS= 193 NCFTS= 101 INFL = 1

M= .450000 KL = -.831890 RL = .038150 SL = -.150000 ELD = 3.333330

OUTPUT

R = .76300 KF= 1.12305 KA= 1.67764 S2= .80250

CPF IS PRISMATIC COEFFICIENT OF FOREBODY. CPA IS PRISMATIC COEFFICIENT OF
AFTERBODY. CP IS OVERALL PRISMATIC COEFFICIENT

CPF = .63886483 CPA = .47708094 CP = .54988369

I	X	Y	DYDX	S	TP
1	0.00000	0.00000	1000000.00000	0.00000	1000000.00000
2	.00100	.00874	4.37030	.00879	75.06305
3	.00200	.01236	3.09220	.01204	50.06186
4	.00300	.01514	2.52630	.01476	37.56069
5	.00400	.01748	2.18912	.01717	30.05953
6	.00500	.01955	1.95911	.01937	25.05838
7	.00600	.02142	1.78939	.02142	21.68580
8	.00700	.02314	1.65753	.02335	18.80608
9	.00800	.02475	1.55127	.02520	16.72161
10	.00900	.02625	1.46326	.02697	15.05380
11	.01000	.02768	1.38883	.02868	13.68903
12	.01100	.02903	1.32479	.03034	12.55154
13	.01200	.03033	1.26894	.03196	

(-R)

47

14	.01300	.03157	1.21967	.03353	11.58887
15	.01400	.03277	1.17577	.03508	10.76358
16	.01500	.03393	1.13633	.03659	10.04817
17	.01600	.03504	1.10064	.03808	9.42206
18	.01700	.03613	1.06814	.03954	8.86947
19	.01800	.03713	1.03838	.04098	8.37817
20	.01900	.03821	1.01190	.04241	7.93847
21	.02000	.03920	.98568	.04381	7.54203
22	.02100	.04013	.96219	.04520	7.18438
23	.02200	.04113	.94030	.04657	6.85861
24	.02300	.04206	.91985	.04793	6.56108
25	.02400	.04297	.90068	.04927	6.28825
26	.02500	.04316	.88266	.05061	6.03716
27	.02600	.04474	.86567	.05193	5.80531
28	.02700	.04559	.84963	.05324	5.59055
29	.02800	.04643	.83444	.05455	5.39106
30	.02900	.04726	.82003	.05584	5.25526
31	.03000	.04808	.80634	.05712	5.03177
32	.03100	.04887	.79331	.05840	4.86942
33	.03200	.04965	.78097	.05967	4.71714
34	.03300	.05044	.76900	.06093	4.57403
35	.03400	.05120	.75764	.06219	4.43928
36	.03500	.05195	.74676	.06343	4.31217
37	.03600	.05269	.73632	.06468	4.19207
38	.03700	.05342	.72630	.06591	4.07841
39	.03800	.05415	.71666	.06714	3.97067
40	.03900	.05486	.70738	.06837	3.86841
41	.04000	.05556	.69845	.06959	3.77122
42	.04100	.05626	.68982	.07080	3.67871
43	.04200	.05694	.68150	.07201	3.59057
44	.04300	.05762	.67346	.07322	3.50647
45	.04400	.05829	.66568	.07442	3.42616
46	.04500	.05895	.65815	.07562	3.34937
47	.04600	.05960	.65086	.07681	3.27588
48	.04700	.06025	.64378	.07800	3.20548
49	.04800	.06089	.63692	.07918	3.13797
50	.04900	.06153	.63026	.08037	3.07317

3.01093	.08154	.62379	.06215	.05000	51
2.95109	.08272	.61750	.06277	.05100	52
2.89352	.08389	.61138	.06339	.05200	53
2.63808	.08506	.60542	.06400	.05300	54
2.78466	.08623	.59962	.06460	.05400	55
2.73315	.08739	.59396	.06520	.05500	56
2.68345	.08855	.58845	.06579	.05600	57
2.63545	.08971	.58307	.06637	.05700	58
2.58908	.09086	.57782	.06695	.05800	59
2.54425	.09201	.57269	.06753	.05900	60
2.50089	.09316	.56769	.06810	.06000	61
2.45891	.09431	.56279	.06866	.06100	62
2.41826	.09546	.55800	.06922	.06200	63
2.37887	.09660	.55332	.06978	.06300	64
2.34068	.09774	.54874	.07033	.06400	65
2.30364	.09888	.54425	.07089	.06500	66
2.26770	.10002	.53986	.07142	.06600	67
2.23280	.10115	.53555	.07196	.06700	68
2.19890	.10228	.53133	.07249	.06800	69
2.16596	.10341	.52719	.07302	.06900	70
2.13393	.10454	.52313	.07354	.07000	71
2.10278	.10567	.51915	.07407	.07100	72
2.07247	.10679	.51523	.07458	.07200	73
2.04296	.10792	.51140	.07510	.07300	74
2.01423	.10904	.50762	.07561	.07400	75
1.38624	.11016	.50392	.07611	.07500	76
1.95897	.11128	.50028	.07661	.07600	77
1.93238	.11239	.49670	.07711	.07700	78
1.90645	.11351	.49318	.07761	.07800	79
1.88115	.11462	.48972	.07810	.07900	80
1.85646	.11573	.48631	.07859	.08000	81
1.83237	.11684	.48296	.07907	.08100	82
1.80883	.11795	.47966	.07955	.08200	83
1.78585	.11906	.47641	.08003	.08300	84
1.76339	.12017	.47321	.08051	.08400	85
1.74144	.12127	.47005	.08098	.08500	86
1.71998	.12237	.46695	.08145	.08600	87
1.69899	.12348	.46388	.08191	.08700	88

89	.08800	.08237	.46087	.12458	1.67846
90	.08900	.08283	.45789	.12568	1.65837
91	.09000	.08329	.45495	.12678	1.63871
92	.09100	.08374	.45206	.12787	1.61946
93	.09200	.08419	.44920	.12897	1.60062
94	.09300	.08464	.44638	.13007	1.58216
95	.09400	.08509	.44360	.13116	1.56407
96	.09500	.08553	.44085	.13225	1.54635
97	.09600	.08597	.43814	.13334	1.52898
98	.09700	.08640	.43546	.13443	1.51195
99	.09800	.08684	.43282	.13552	1.49525
100	.09900	.08727	.43020	.13661	1.47887
101	.10000	.08770	.42762	.13770	1.46280
102	.10200	.08955	.42254	.13987	1.43156
103	.10500	.08981	.41514	.14312	1.38681
104	.11000	.09185	.40333	.14851	1.31735
105	.12000	.09577	.38142	.15921	1.19477
106	.13000	.09949	.36140	.16985	1.08980
107	.14000	.10301	.34290	.18042	.99868
108	.15000	.10635	.32566	.19094	.91866
109	.16000	.10952	.30946	.20140	.84766
110	.17000	.11254	.29414	.21183	.78409
111	.18000	.11541	.27957	.22221	.72673
112	.19000	.11813	.26564	.23256	.67458
113	.20000	.12072	.25226	.24287	.62638
114	.21000	.12318	.23937	.25315	.58298
115	.22000	.12551	.22691	.26341	.54236
116	.23000	.12772	.21482	.27364	.50459
117	.24000	.12981	.20307	.28384	.46931
118	.25000	.13178	.19162	.29402	.43622
119	.26000	.13364	.18044	.30418	.40505
120	.27000	.13539	.16951	.31433	.37559
121	.28000	.13703	.15880	.32445	.34765
122	.29000	.13857	.14829	.33456	.32105
123	.30000	.14000	.13798	.34465	.29567
124	.31000	.14133	.12784	.35474	.27136
125	.32000	.14256	.11786	.36481	.24803

126	.33000	.14369	.10804	.37486	.22558
127	.34000	.14472	.09436	.38491	.20391
128	.35000	.14565	.08882	.39495	.18294
129	.36000	.14659	.07941	.40498	.16262
130	.37000	.14724	.07013	.41501	.14288
131	.38000	.14790	.06096	.42503	.12366
132	.39000	.14846	.05192	.43504	.10491
133	.40000	.14894	.04298	.44505	.08658
134	.41000	.14932	.03417	.45505	.06864
135	.42000	.14962	.02546	.46506	.05105
136	.43000	.14983	.01686	.47506	.03376
137	.44000	.14996	.00837	.48506	.01675
138	.45000	.15000	.00000	.49506	.00000
139	.46000	.14996	-.00892	.50506	-.01785
140	.47000	.14982	-.01894	.51506	-.03793
141	.48000	.14957	-.02991	.52507	-.06000
142	.49000	.14922	-.04170	.53507	-.08384
143	.50000	.14874	-.05417	.54509	-.10926
144	.51000	.14813	-.06722	.55511	-.13613
145	.52000	.14739	-.08074	.56514	-.16433
146	.53000	.14652	-.09463	.57519	-.19377
147	.54000	.14550	-.10882	.58525	-.22438
148	.55000	.14434	-.12322	.59532	-.25612
149	.56000	.14303	-.13777	.60542	-.28896
150	.57000	.14158	-.15239	.61553	-.32290
151	.58000	.13999	-.16703	.62567	-.35795
152	.59000	.13824	-.18163	.63584	-.39415
153	.60000	.13635	-.19614	.64603	-.43153
154	.61000	.13432	-.21051	.65625	-.47016
155	.62000	.13214	-.22470	.66650	-.51012
156	.63000	.12983	-.23866	.67678	-.55150
157	.64000	.12737	-.25237	.68709	-.59440
158	.65000	.12478	-.26577	.69744	-.63896
159	.66000	.12206	-.27893	.70782	-.68533
160	.67000	.11921	-.29153	.71823	-.73368
161	.68000	.11623	-.30382	.72869	-.78419
162	.69000	.11313	-.31567	.73917	-.83709
163	.70000	.10992	-.32705	.74969	-.89264

164	.71000	.10659	−.33793	.76025	−.95111
165	.72000	.10316	−.34828	.77084	−1.01284
166	.73000	.09963	−.35806	.78146	−1.07820
167	.74000	.09600	−.36725	.79211	−1.14764
168	.75000	.09228	−.37580	.80280	−1.22165
169	.76000	.08849	−.38368	.81351	−1.30081
170	.77000	.08461	−.39086	.82424	−1.38582
171	.78000	.08067	−.39730	.83500	−1.47748
172	.79000	.07667	−.40296	.84578	−1.57675
173	.80000	.07262	−.40780	.85658	−1.68476
174	.81000	.06852	−.41176	.86740	−1.80289
175	.82000	.06438	−.41480	.87823	−1.93281
176	.83000	.06022	−.41687	.88906	−2.07658
177	.84000	.05605	−.41789	.89990	−2.23674
178	.85000	.05187	−.41781	.91073	−2.41651
179	.86000	.04770	−.41655	.92157	−2.61998
180	.87000	.04354	−.41402	.93239	−2.85246
181	.88000	.03942	−.41011	.94320	−3.12098
182	.89000	.03535	−.40471	.95399	−3.43503
183	.90000	.03133	−.39769	.96475	−3.80775
184	.91000	.02740	−.38886	.97548	−4.25789
185	.92000	.02356	−.37803	.98617	−4.81321
186	.93000	.01985	−.36493	.99681	−5.51666
187	.94000	.01627	−.34923	1.00741	−6.43854
188	.95000	.01287	−.33047	1.01794	−7.70285
189	.96000	.00967	−.30804	1.02840	−3.55170
190	.97000	.00673	−.28100	1.03879	−12.53469
191	.98000	.00407	−.24789	1.04909	−18.24949
192	.99000	.00180	−.20608	1.05930	−34.61885
193	1.00000	.00000	−.15000	1.06941	**********

VOLUME/L3 = .0388690

L IS OVERALL LENGTH. LF IS LENGTH OF FOREBODY. LA IS LENGTH OF AFTERBODY.

LF/L = .45000   LA/L = .55000

52

AREAF IS SURFACE AREA OF FOREBODY. AREAA IS SURFACE AREA OF AFTERBODY. AREAT IS TOTAL
SURFACE AREA.

AREAF/L2   =   .33919787 AREAA/L2   =   .32020114 ARFAT/L2   =   .65939901

FOREBODY ARC LENGTH/L =   .495060   AFTERBODY   ARC LENGTH/L =   .574354   TOTAL

ARC LEGNTH/L =   1.069414

APPENDIX B

DESCRIPTION, GLOSSARY, LISTING, AND SAMPLE
RUN OF DPIN2

DESCRIPTION OF DPIN2

This program uses the polynomials of Landweber and Gertler[19] to compute the offsets and slopes of a David Taylor Model Basin Series 58 body. This is a streamlined body of revolution in which $Y(I)$ is the square root of a septic in $X(I)$, where the axis of symmetry is the x-axis, the nose is at the origin, and the tail is at $x = 1.0$. Coefficients in the septic are specified by geometric parameters. The user is warned that, in contrast to DPIN1 and DPIN3, no checks are provided in DPIN2 to ensure that the geometric parameters specified are within admissible ranges. Instead, it is assumed that the user either is describing an existing Series 58 body or has Reference 19 available so that the parameters have been selected for him or he can readily check their admissibility.

As calculated by this program, the bodies are represented by series of frustums of cones with generating axis along the axis of revolution since the body shapes are formed by straight-line segments between points defined by pairs of x- and y- coordinates. One feature of the program is that the segment lengths or step sizes over the foremost portion of the body are one-tenth as large as those over the rest of it. (A different ratio of step sizes could be attained by a minor modification to the appropriate DPIN and to DPOUT.) The change from the smaller to the larger step size is made over a total of three steps in such a way that no step is more than twice as large as the one preceding it. Experience in operation of the axisymmetric potential-flow program has shown the desirability of this relatively gradual change.

Input variables to the program consist of the integers NPTS and NCPTS and the floating-point numbers M, RO, Rl, CP, and ELD. NPTS and NCPTS are the total number of points on the body and the number of

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[19] Landweber, L. and M. Gertler, "Mathematical Formulation of Bodies of Revolution," David Taylor Model Basin Report 719 (Sep 1950).

55

closely spaced points. M is the ratio of the axial distance from nose to maximum diameter to the total length. RO is the nose radius of curvature times the total length divided by the square of the maximum diameter. R1 is the tail radius of curvature times the total length divided by the square of the maximum diameter. CP is the prismatic coefficient, and ELD is the ratio of total length to maximum diameter.

After DPIN2 has read its seven input variables, it writes them out. Then it evaluates the septic and its derivative at each point and finds the offsets Y(I) and slope DYDX(I) in terms of these. The increment in arc length DS, the wetted area, and the geometric function TP(I), which is used for predicting boundary-layer transition, are also computed at each point. Then I, X, Y, DYDX, S, and TP are written out for each point. Finally the total volume, wetted area, and arc length are computed and written out. X(I), Y(I), DYDX(I), and the volume, wetted area, length-to-diameter ratio, and the numbers of total points and close points are also written on tape for use by subsequent programs.

DPIN2 - GLOSSARY

The following glossary of variables used in DPIN2 is arranged alphabetically by FORTRAN variable name.

FORTRAN Variable Name	Variable	Definition
AT	$A^{(t)}/L^2$	Total wetted area divided by square of total length
AO	α_o	Coefficient used in calculation of ROX
A1	α_1	Coefficient used in calculation of ROX
BO	β_o	Coefficient used in calculation of R1X
B1	β_1	Coefficient used in calculation of R1X
CP	C_p	Prismatic coefficient

FORTRAN Variable Name	Variable	Definition
DP	$\dfrac{dP}{dx}$	Derivative of PX with respect to X
DQ	$\dfrac{dQ}{dx}$	Derivative of QX with respect to X
DRO	$\dfrac{dR_o}{dx}$	Derivative of ROX with respect to X
DR1	$\dfrac{dR_1}{dx}$	Derivative of R1X with respect to X
DS	ds/L	Increment in arc length s divided by total length
DX	dx/L	Increment in axial length x divided by total length
DYDX	$\dfrac{dy}{dx}$	Slope; dimensioned to be a function of I
DY2DX	$\dfrac{1}{L}\dfrac{dy^2}{dx}$	Derivative of y^2 with respect to x, divided by total length
DO	δ_o	Coefficient used in calculation of QX
D1	δ_1	Coefficient used in calculation of QX
D2	δ_2	Coefficient used in calculation of QX
ELD	L/MAX. DIAMETER	Ratio of total length to maximum diameter
G	g	Coefficient used in calculation of PX
I	i	Integer which increases from 1 at the nose to NCPTS at the point where step size begins increasing, thence to NPTS at the tail
M	m	Ratio of forebody length to total length
M1	1. - m	Ratio of afterbody length to total length

FORTRAN Variable Name	Variable	Definition
NCPTS	$n^{(c)}$	Number of the point downstream of which the point spacing begins to increase
NC1	$n^{(c)} + 1$	
NC2	$n^{(c)} + 2$	
NC3	$n^{(c)} + 3$	
NC4	$n^{(c)} + 4$	
NPTS	n	Total number of points
PI	π	Ratio of the circumference of a circle to its diameter
PX	$P(x)$	Polynomial in X, X1, and XM
QX	$Q(x)$	Polynomial in X and X1
RO	r_o	Dimensional radius of curvature at nose, multiplied by body length and divided by the square of the maximum diameter
ROX	$R_o(x)$	Polynomial in X, X1, and XM
R1	r_1	Dimensional radius of curvature of tail multiplied by the body length and divided by the square of the maximum diameter
R1X	$R_1(x)$	Polynomial in X, X1, and XM
S	s/L	Arc length at arbitrary X divided by total length; dimensioned to be a function of I
ST	$s^{(t)}/L$	Total arc length divided by total length
TP	$\dfrac{L}{ELD\ y(x)} \dfrac{dy}{dx}$	Function used in DPOUT to predict transition; dimensioned to be a function of I
VL3	V/L^3	Volume of body divided by cube of total length

FORTRAN Variable Name	Variable	Definition
X	x/L	Axial coordinate divided by total length; dimensioned to be a function of I
XM	$\dfrac{x}{L} - m$	x stretched to increase from $-m$ at the nose to $1 - m$ at the tail
XX	x/L	Axial coordinate, identical to X except that it is not dimensioned as a function of I
X1	$\dfrac{x}{L} - 1$	x normalized to increase from $X1 = -1$ at the nose to $X1 = 0$ at the tail
Y	y/L	Body radius divided by total length; dimensioned to be a function of I
Y2	y^2/L^2	Y squared

LISTING AND SAMPLE RUN OF DPIN2

```
      PROGRAMDPIN2(INPUT,OUTPUT,TAPE60,TAPE61,TAPE5=INPUT,TAPE6=OUTPUT,T
     UAPE88)
      REAL M, M1
C     THIS PROGRAM COMPUTES THE OFFSETS, SLOPE, AND WETTED AREA OF A
C     SERIES 58 BODY, ACCORDING TO LANDWEBER AND GERTLER, DTMB REPORT
C     719, 1950
      DIMENSION X(202),Y(202),DYDX(202),S(202),TP(202)
      READ(5,16) NPTS,NCPTS
 16   FORMAT(2I10)
      WRITE(6,17) NPTS,NCPTS
 17   FORMAT(1H1, 1X,*NPTS = *, I5, 3X, *NCPTS = *, I5)
 7    READ(5,1) M, RO, R1, CP, ELD
      IF(EOF(5))8,9
 1    FORMAT(5F10.6)
 9    WRITE(6,5) M, RO, R1, CP, ELD
 5    FORMAT( //,10X*INPUT*//* M=*, F10.6,* RO=*, F10.6,* R1 = *,
     +F10.6, * CP = *, F10.6,* ELD = *, F10.6)
      WRITE (6,3)
 3    FORMAT(//4X,*I*, 9X,*X*, 14X, *Y*, 14X, *DYDX*, 11X, *S*, 14X,
     +,*TP*, /)
      M1 = 1.-M
      DX = .001
      X(1) = 0.
      Y(1) = 0.
      PI = 3.14159
      S(1) = 0.
      AT = 0.
      NC1 = NCPTS+1
      NC2 = NCPTS+2
      NC3 = NCPTS+3
      NC4 = NCPTS+4
      A0 = 1./(M*M)
      A1 = -3.5*(1.-4.*M+5.*M*M)/(M*M*(2.-7.*M+7.*M*M))
      B0 = (5.-14.*M+10.5*M*M)/(M1*M1*(2.-7.*M+7.*M*M))
      R1 = -3.5*(2.-6.*M+5.*M*M)/(M1*M1*(2.-7.*M+7.*M*M))
      G = 52.5/(2.-7.*M+7.*M*M)
```

```
      DO = .75*(2.-8.*M+7.*M*M)/(M*M*M1*M1*M1*(2.-7.*M+7.*M*M))
      D1 = -(1.-2.*M-7.*M*M+10.5*M*M*M)/(M*M*M*M1*M1*M1*(2.-7.*M
     ++7.*M*M))
      D2 = 1.75*(1.-5.*M+5.*M*M)/(M*M*M*M1*M1*M1*(2.-7.*M+7.*M*M))
      DO 2 I=2,NPTS
      IF(I.EQ.NC1) DX = .002
      IF(I .EQ. NO2) DX = .003
      IF(I .EQ. NC3) DX = .005
      IF(I .EQ. NC4) DX = .010
      X(I)=X(I-1)+DX
      XX = X(I)
      X1 = XX-1.
      XM = XX-M
      ROX = XX*X1*X1*XM*XM*(A0+A1*XX)
      R1X = XX*XX*X1*XM*XM*(B0+B1*XX)
      PX = XX*XX*X1*X1*XM*XM*G
      QX = XX*XX*X1*X1*(D0+D1*XX+D2*XX*XX)
      Y2 = 2.*R0*ROX+2.*R1*R1X+CP*PX+QX
      Y(I) = SQRT(Y2)/ELD
      DRO = ROX*(1./XX+2./X1+2./XM+A1/(A0+A1*XX))
      DR1 = R1X*(2./XX+1./X1+2./XM+B1/(B0+B1*XX))
      DP = PX*(2./XX+2./X1+2./XM)
      DQ = QX*(2./XX+2./X1+(D1+2.*D2*XX)/(D0+D1*XX+D2*XX*XX))
      DY2DX = 2.*R0*DRO+2.*R1*DR1+CP*DP+DQ
      DYDX(I) = .5*DY2DX/(Y(I)*ELD*ELD)
      DYDX(NPTS) = DYDX(NPTS-1)
      DS = DX*SQRT(1.+DYDX(I)*DYDX(I))
      IF (I.NE.2) GO TO 19
      S(2) = SQRT((X(2)-X(1))*(X(2)-X(1))+(Y(2)-Y(1))*(Y(2)-Y(1)))
      GO TO 27
   19 CONTINUE
      S(I) = S(I-1) + DS
   27 CONTINUE
      ST = S(I)
      TP(I) = DYDX(I)/(Y(I)*ELD)
      AT = AT+2.*PI*Y(I)*DS
    2 CONTINUE
      WRITE(6,6)( I, X(I), Y(I), DYDX(I),S(I),TP(I),I=1,NPTS)
    6 FORMAT(2X, I3, 5F15.5)
      WRITE(60)(X(I),Y(I),I=1,NPTS)
      ENDFILE 60
      WRITE(61)(DYDX(I),I=1,NPTS)
      VL3 = .25*PI*CP/(ELD*ELD)
      WRITE(6,15) VL3
   15 FORMAT(/1X,* VOLUME/L3  = *,F15.7/)
      WRITE(88) VL3,AT, ELD, NPTS, NCPTS
      WRITE (6,25)     AT
   25 FORMAT(/1X,* WETTED AREA/L2 =  *, F10.6)
      WRITE (6,4) ST
    4 FORMAT (//, 1X, * TOTAL ARC LENGTH/L = * , F10.6)
      GOTO7
    8 CONTINUE
      END
```

NPTS = 193   NCPTS = 101

INPUT

M= .400000 RO= .500000 R1 = .100000 CP = .600000 ELD = 7.000000

I	X	Y	DYDX	S	TP
			-R		-R
1	0.00000	0.00000	-R	0.00000	-R
2	.00100	.00452	2.26156	.00463	71.48710
3	.00200	.00639	1.60106	.00652	35.77155
4	.00300	.00783	1.30876	.00816	23.86553
5	.00400	.00905	1.13467	.00968	17.91191
6	.00500	.01012	1.01595	.01110	14.33924
7	.00600	.01109	.92837	.01247	11.95706
8	.00700	.01198	.86034	.01379	10.25516
9	.00800	.01282	.80552	.01507	8.97844
10	.00900	.01360	.76013	.01633	7.98517
11	.01000	.01434	.72173	.01756	7.19033
12	.01100	.01504	.68870	.01877	6.53979
13	.01200	.01572	.65989	.01997	5.99749
14	.01300	.01637	.63446	.02116	5.53844
15	.01400	.01699	.61180	.02233	5.14482
16	.01500	.01759	.59144	.02349	4.80353
17	.01600	.01817	.57301	.02464	4.50476
18	.01700	.01874	.55622	.02579	4.24102
19	.01800	.01928	.54084	.02692	4.00646
20	.01900	.01982	.52667	.02805	3.79648
21	.02000	.02034	.51357	.02918	3.60739
22	.02100	.02085	.50141	.03030	3.43622
23	.02200	.02134	.49007	.03141	3.28051
24	.02300	.02183	.47947	.03252	3.13825
25	.02400	.02230	.46952	.03362	3.00776
26	.02500	.02277	.46016	.03472	2.88763
27	.02600	.02322	.45134	.03582	2.77667
28	.02700	.02367	.44299	.03692	2.67385

29	.02800	.02411	.43509	.03801	2.57831
30	.02900	.02454	.42758	.03909	2.48929
31	.03000	.02496	.42044	.04018	2.40614
32	.03100	.02538	.41363	.04126	2.32829
33	.03200	.02579	.40714	.04234	2.25525
34	.03300	.02619	.40092	.04342	2.18659
35	.03400	.02659	.39497	.04449	2.12190
36	.03500	.02698	.38927	.04557	2.06086
37	.03600	.02737	.38379	.04664	2.00316
38	.03700	.02775	.37852	.04771	1.94854
39	.03800	.02813	.37345	.04877	1.89674
40	.03900	.02850	.36856	.04984	1.84755
41	.04000	.02886	.36385	.05090	1.80077
42	.04100	.02923	.35930	.05197	1.75624
43	.04200	.02958	.35489	.05303	1.71379
44	.04300	.02994	.35064	.05409	1.67327
45	.04400	.03028	.34651	.05514	1.63455
46	.04500	.03063	.34251	.05620	1.59752
47	.04600	.03097	.33863	.05726	1.56206
48	.04700	.03131	.33487	.05831	1.52808
49	.04800	.03164	.33121	.05937	1.49548
50	.04900	.03197	.32765	.06042	1.46417
51	.05000	.03229	.32419	.06147	1.43409
52	.05100	.03262	.32083	.06252	1.40515
53	.05200	.03294	.31754	.06357	1.37730
54	.05300	.03325	.31434	.06462	1.35047
55	.05400	.03357	.31122	.06566	1.32460
56	.05500	.03387	.30818	.06671	1.29965
57	.05600	.03418	.30520	.06776	1.27556
58	.05700	.03449	.30230	.06880	1.25229
59	.05800	.03479	.29946	.06984	1.22979
60	.05900	.03508	.29668	.07089	1.20804
61	.06000	.03538	.29396	.07193	1.18698
62	.06100	.03567	.29130	.07297	1.16659
63	.06200	.03596	.28870	.07401	1.14683
64	.06300	.03625	.28614	.07505	1.12768
65	.06400	.03653	.28364	.07609	1.10910

66	.06500	.03682	.28119	.07713	1.09108
67	.06600	.03710	.27878	.07817	1.07358
68	.06700	.03737	.27642	.07921	1.05658
69	.06800	.03765	.27410	.08024	1.04006
70	.06900	.03792	.27183	.08128	1.02400
71	.07000	.03819	.26959	.08232	1.00837
72	.07100	.03846	.26739	.08335	.99317
73	.07200	.03873	.26523	.08439	.97837
74	.07300	.03899	.26311	.08542	.96396
75	.07400	.03925	.26102	.08645	.94992
76	.07500	.03951	.25896	.08749	.93624
77	.07600	.03977	.25694	.08852	.92290
78	.07700	.04003	.25495	.08955	.90989
79	.07800	.04028	.25299	.09058	.89720
80	.07900	.04053	.25106	.09161	.88481
81	.08000	.04078	.24915	.09264	.87272
82	.08100	.04103	.24728	.09367	.86090
83	.08200	.04128	.24543	.09470	.84937
84	.08300	.04152	.24360	.09573	.83809
85	.08400	.04177	.24180	.09676	.82707
86	.08500	.04201	.24003	.09779	.81629
87	.08600	.04225	.23828	.09882	.80575
88	.08700	.04248	.23655	.09985	.79544
89	.08800	.04272	.23485	.10087	.78535
90	.08900	.04295	.23316	.10190	.77547
91	.09000	.04319	.23150	.10293	.76580
92	.09100	.04342	.22986	.10395	.75632
93	.09200	.04365	.22823	.10498	.74704
94	.09300	.04387	.22663	.10600	.73795
95	.09400	.04410	.22505	.10703	.72904
96	.09500	.04432	.22348	.10805	.72030
97	.09600	.04455	.22193	.10908	.71174
98	.09700	.04477	.22040	.11010	.70334
99	.09800	.04499	.21889	.11112	.69510
100	.09900	.04520	.21739	.11215	.68701
101	.10000	.04542	.21591	.11317	.67907
102	.10200	.04585	.21299	.11522	.66364

103	.10500	.04648	.20873	.11828	.64151
104	.11000	.04751	.20190	.12338	.60711
105	.12000	.04946	.18914	.13356	.54627
106	.13000	.05130	.17739	.14371	.49402
107	.14000	.05301	.16646	.15385	.44857
108	.15000	.05463	.15624	.16397	.40858
109	.16000	.05614	.14660	.17408	.37305
110	.17000	.05756	.13749	.18417	.34123
111	.18000	.05889	.12882	.19426	.31249
112	.19000	.06014	.12056	.20433	.28639
113	.20000	.06130	.11265	.21439	.26252
114	.21000	.06239	.10507	.22445	.24058
115	.22000	.06341	.09779	.23450	.22032
116	.23000	.06435	.09077	.24454	.20152
117	.24000	.06522	.08401	.25457	.18401
118	.25000	.06603	.07748	.26460	.16763
119	.26000	.06677	.07117	.27463	.15226
120	.27000	.06745	.06506	.28465	.13779
121	.28000	.06808	.05914	.29467	.12411
122	.29000	.06864	.05341	.30468	.11116
123	.30000	.06914	.04784	.31469	.09885
124	.31000	.06960	.04244	.32470	.08712
125	.32000	.06999	.03719	.33471	.07591
126	.33000	.07034	.03209	.34471	.06518
127	.34000	.07064	.02714	.35472	.05488
128	.35000	.07088	.02231	.36472	.04497
129	.36000	.07108	.01762	.37472	.03540
130	.37000	.07124	.01304	.38472	.02615
131	.38000	.07134	.00858	.39472	.01719
132	.39000	.07141	.00424	.40472	.00848
133	.40000	.07143	-.00000	.41472	-.00000
134	.41000	.07141	-.00414	.42472	-.00828
135	.42000	.07135	-.00818	.43472	-.01638
136	.43000	.07124	-.01213	.44472	-.02432
137	.44000	.07110	-.01599	.45472	-.03213
138	.45000	.07093	-.01977	.46473	-.03982
139	.46000	.07071	-.02347	.47473	-.04742

140	.47000	.07046	-.02710	.48473	-.05495
141	.48000	.07017	-.03066	.49474	-.06243
142	.49000	.06984	-.03416	.50474	-.06987
143	.50000	.06948	-.03760	.51475	-.07730
144	.51000	.06909	-.04098	.52476	-.08473
145	.52000	.06866	-.04431	.53477	-.09219
146	.53000	.06820	-.04760	.54478	-.09970
147	.54000	.06771	-.05085	.55479	-.10728
148	.55000	.06719	-.05406	.56481	-.11494
149	.56000	.06663	-.05724	.57482	-.12272
150	.57000	.06604	-.06039	.58484	-.13063
151	.58000	.06542	-.06352	.59486	-.13871
152	.59000	.06477	-.06664	.60488	-.14697
153	.60000	.06409	-.06974	.61491	-.15545
154	.61000	.06338	-.07284	.62493	-.16418
155	.62000	.06263	-.07593	.63496	-.17318
156	.63000	.06186	-.07903	.64499	-.18250
157	.64000	.06105	-.08213	.65503	-.19217
158	.65000	.06022	-.08525	.66506	-.20224
159	.66000	.05935	-.08838	.67510	-.21274
160	.67000	.05845	-.09154	.68515	-.22373
161	.68000	.05752	-.09472	.69519	-.23526
162	.69000	.05655	-.09794	.70524	-.24740
163	.70000	.05556	-.10120	.71529	-.26021
164	.71000	.05453	-.10450	.72534	-.27377
165	.72000	.05347	-.10785	.73540	-.28816
166	.73000	.05237	-.11126	.74546	-.30347
167	.74000	.05124	-.11472	.75553	-.31983
168	.75000	.05008	-.11826	.76560	-.33735
169	.76000	.04888	-.12187	.77567	-.35618
170	.77000	.04764	-.12555	.78575	-.37648
171	.78000	.04637	-.12933	.79583	-.39846
172	.79000	.04505	-.13319	.80592	-.42233
173	.80000	.04370	-.13716	.81602	-.44836
174	.81000	.04231	-.14124	.82612	-.47689
175	.82000	.04088	-.14545	.83622	-.50830
176	.83000	.03940	-.14978	.84633	-.54306

177	.84000	-.15426	.03788	.85645	-.58176
178	.85000	-.15891	.03632	.86658	-.62512
179	.86000	-.16374	.03470	.87671	-.67407
180	.87000	-.16878	.03304	.88685	-.72978
181	.88000	-.17407	.03133	.89700	-.79382
182	.89000	-.17965	.02956	.90716	-.86827
183	.90000	-.18558	.02773	.91733	-.95599
184	.91000	-.19196	.02584	.92751	-1.06106
185	.92000	-.19892	.02389	.93771	-1.18947
186	.93000	-.20668	.02186	.94792	-1.35047
187	.94000	-.21560	.01975	.95815	-1.55923
188	.95000	-.22630	.01755	.96840	-1.84255
189	.96000	-.24002	.01522	.97869	-2.25323
190	.97000	-.25949	.01273	.98902	-2.91282
191	.98000	-.29230	.00998	.99944	-4.18206
192	.99000	-.37060	.00674	1.01010	-7.85205
193	1.00000	-.37060	.00000	1.02077	-2457706.77897

VOLUME/L3 = .0096171

WETTED AREA/L2 = .329239

TOTAL ARC LENGTH/L = 1.020767

APPENDIX C

DESCRIPTION, GLOSSARY, LISTING, AND SAMPLE
RUN OF DPIN3

DESCRIPTION OF DPIN3

This program uses the polynomials of Granville[20] to compute the offsets and slopes of a streamlined body of revolution formed by a forebody with rounded nose, a parallel middlebody of maximum diameter, and an afterbody with pointed tail. The axis of symmetry is the x-axis, the nose is at the origin, and the tail is at $x = 1.0$. On the forebody, y is equal to the square root of a quintic in x; on the middlebody, it is (by definition) constant; and on the afterbody, it is equal to the square root of a septic. Coefficients in the quintic and septic are specified by geometric parameters which are input variables, together with the requirements that the slope dy/dx and the curvature d^2y/dx^2 be continuous at the forebody-middlebody and middlebody-afterbody junctures, and hence be zero there.

As calculated by this program, the bodies are represented by series of frustums of cones with generating axis along the axis of revolution, since the body shapes are formed by straight-line segments between points defined by pairs of x- and y- coordinates. One feature of the program is that the segment lengths or step sizes over the foremost portion of the body are one-tenth as large as those over the rest of it. (A different ratio of step sizes could be attained by a minor modification to the appropriate DPIN and to DPOUT.) The change from the smaller to the larger step size is made over a total of three steps in such a way that no step is more than twice as large as the one preceding it. Experience in operation of the axisymmetric potential-flow program has shown the desirability of this relatively gradual change.

Input variables to the program consist of the integers NPTS, NCPTS, and INFL and the floating-point numbers, MF, MA, KFL, KAL, RL, SL, and

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[20]Granville, P. S., "Geometrical Characteristics of Noses and Tails for Parallel Middle Bodies," NSRDC Report 3763 (Dec 1972); also International Shipbuilding Progress, Vol. 21, No. 233, pp. 3-19 (Jan 1974).

69

ELD. NPTS and NCPTS are the total number of points on the body and the
number of closely spaced points. INFL is the maximum number of inflec-
tion points permitted on the afterbody and must be either 0 or 1. MF is
the ratio of forebody length to total length, KFL is the rate of change
(with x) of curvature at the forebody-middlebody juncture, KAL is the
rate of change of curvature at the middlebody-afterbody juncture, RL is
the radius of curvature at the nose, SL is the slope at the tail, and
ELD is the ratio of total length to maximum diameter. KFL, KAL, RL, and
SL are expressed in coordinates scaled so that the total length of the
body is 1. In order to use the polynomials,[20] they are transformed to
stretched coordinates in which the forebody or afterbody length and the
maximum radius each equals 1. Thus the coefficients in the quintic for
the forebody are R, the stretched nose radius, and KF, the stretched
rate of change of curvature at the forebody-middlebody juncture. The
coefficients in the septic in the afterbody are KA, the stretched rate
of change of curvature at the middlebody-afterbody juncture, and S2, the
square of SP, the stretched slope at the tail. KA and SP have their
signs reversed so as to be ordinarily positive. Granville[20] avoids
undesirable bulges, zeros, and inflection points on the forebody by
requiring R and KF to lie in an admissible region when graphed (see
Figures 2-4 of Reference 20, in which they are denoted by r and $\tilde{k}_1$).
In the same way, undesirable afterbodies are excluded by requiring that
S2 and KA lie in one of two admissible regions when graphed (see Figures
5 and 6 of Reference 20, in which they are denoted by s^2 and $\tilde{k}_1$), accord-
ing to whether zero or one inflection points are to be allowed on the
afterbody. Instead of introducing the complications associated with
numerical representation of the curves which delineate the admissible
regions on these graphs, DPIN3 uses a different method of checking the
occurrence of bulges and points of inflection: as the slope at each
point is computed, it is compared with zero and the slope at the pre-
vious point. If at points on the forebody the slope is negative or
greater than the previous slope, the program prints out a message that
the forebody parameters are inadmissible and stops. At points on the
afterbody, the program prints out the corresponding message and stops

70

if the slope is positive or, if no inflection points are permitted (INFL = 0), the slope is greater than the previous slope. If one inflection point is permitted (INFL = 1), the slope is allowed to exceed the previous slope over a range of points, past which it may become less than the previous slope over one range but must not exceed the previous slope over a second range.

The program user may wish to modify DPIN3 so that KF, KA, R, and S2 (or its square root) are used as input rather than the unstretched KFL, KAL, RL, and SL. Furthermore, he may wish to replace either KF or R with CDF, the forebody prismatic coefficient, or to replace either KA or S2 with CPA, the afterbody prismatic coefficient since Equations (103) and (104) in Granville[20] present linear relations between these respective triads of geometric parameters.

After DPIN3 has read its ten input variables, it writes them out, then computes the forebody, afterbody, and overall prismatic coefficients and writes them out. Then it finds the appropriate step size DX and proceeds to calculate the offsets Y(I) at each point along the forebody and afterbody by taking the square root of the appropriate polynomial. The slope DYDX(I) and increment in arc length DS are calculated by using the derivative of the polynomial. The wetted area and a geometric function TP(I), which is used for predicting boundary-layer transition, are also computed at each point. Then I, X, Y, DYDX, S, and TP are written out for each point. Finally the volume, and forebody, middlebody, afterbody, and overall wetted areas and arc lengths are written out. X(I), Y(I), and the length-to-diameter ratio, and numbers of total points and closely spaced points are also written on tape for use by subsequent programs.

DPIN3 - GLOSSARY

The following glossary of variables used in DPIN3 is arranged alphabetically by FORTRAN variable name.

71

FORTRAN Variable Name	Variable	Definition
AA	$A^{(a)}/L^2$	Wetted area of afterbody divided by square of total length
AF	$A^{(f)}/L^2$	Wetted area of forebody divided by square of total length
AM	$A^{(m)}/L^2$	Wetted area of middlebody divided by square of total length
AT	$A^{(t)}/L^2$	Total wetted area divided by square of total length
CP	C_p	Prismatic coefficient of complete body
CPA	$C_p^{(a)}$	Prismatic coefficient of afterbody
CPF	$C_p^{(f)}$	Prismatic coefficient of forebody
DS	ds/L	Increment in arc length s divided by total length
DX	dx/L	Increment in axial length x divided by total length
DYDX	$\frac{dy}{dx}$	Slope; dimensioned to be a function of I
ELD	L/MAX. DIAMETER	Ratio of total length to maximum diameter
I	i	Integer which increases from 1 at the nose to NCPTS at the point where step size starts increasing, hence to NPTS at the tail
INFL		Control variable which specifies the maximum number of inflection points allowed on the afterbody; always input as 0 or 1

FORTRAN Variable Name	Variable	Definition
KA	$\tilde{k}_1(a)$	Rate of change of curvature at middlebody-afterbody juncture, normalized for unit afterbody length and unit maximum radius, with sign reversed so as to be ordinarily positive
KAL	$L^2 \dfrac{d^3 y}{dx^3}\bigg|$ (middlebody-afterbody juncture)	Rate of change of curvature at middlebody-afterbody juncture times square of total length
KF	$\tilde{k}_1(f)$	Rate of change of curvature at forebody-middlebody juncture, normalized for unit forebody length and unit maximum radius
KFL	$L^2 \dfrac{d^3 y}{dx^2}\bigg|$ (forebody-middlebody juncture)	Rate of change of curvature at forebody-middlebody juncture times square of total length
MA	$m^{(a)}$	Ratio of length of forebody plus middlebody to total length
MA1	$1 - m^{(a)}$	Ratio of afterbody length to total length
MF	$m^{(f)}$	Ratio of forebody length to total length
NCPTS	$n^{(c)}$	Number of the point downstream of which the point spacing begins to increase
NC1	$n^{(c)} + 1$	
NC2	$n^{(c)} + 2$	

FORTRAN Variable Name	Variable	Definition
NC3	$n^{(c)} + 3$	
NC4	$n^{(c)} + 4$	
NPTS	n	Total number of points
PI	π	Ratio of the circumference of a circle to its diameter
R	r	Radius of curvature at nose, normalized for unit forebody length and unit maximum radius
RL	$\left. \frac{1}{L} \frac{dx^2}{dy^2} \right\vert_{(nose)}$	Radius of curvature of nose divided by total length
S	s/L	Arc length at arbitrary x divided by total length; dimensioned to be a function of I
SA	$s^{(a)}/L$	Arc length of afterbody divided by total length
SF	$s^{(f)}/L$	Arc length of forebody divided by total length
SL	$\left. \frac{dy}{dx} \right\vert_{(tail)}$	Slope at tail
SM	$s^{(m)}/L$	Arc length of middlebody divided by total length
SP	$s^{(p)}$	Slope at tail, normalized for unit afterbody length and unit maximum radius, with sign reversed so as to be ordinarily positive
ST	$s^{(t)}$	Total arc length divided by total length

74

FORTRAN Variable Name	Variable	Definition
S2	$s^{(p)2}$	SP squared
TP	$\dfrac{1}{ELD}\dfrac{1}{y(x)}\dfrac{dy}{dx}$	Function used in DPOUT to predict transition; dimensioned to be a function of I
VL3	V/L^3	Volume of body divided by cube of total length
X	x/L	Axial coordinate divided by total length; dimensioned to be a function of I
XA	$\dfrac{1-x/L}{1-m^{(a)}}$	Reversed x, normalized to increase from XA = 0 at tail to XA - 1 at middlebody-afterbody juncture
XA1	$\dfrac{m^{(a)}-x/L}{1-m^{(a)}}$	Reversed x, normalized to increase from XA1 = -1 at tail to XA1 = 0 at middlebody-afterbody juncture
XF	$\dfrac{x/L}{m^{(f)}}$	x normalized to increase from XF = 0 at nose to XF = 1 at forebody-middlebody juncture
XF1	$\dfrac{x/L-m^{(f)}}{m^{(f)}}$	x normalized to increase from XF1 = -1 at nose to XF1 = 0 at forebody-middlebody juncture
XX		Axial variable, indentical to X except that it is not dimensioned as a function of I
Y	y/L	Body radius divided by total length; dimensioned to be a function of I

LISTING AND SAMPLE RUN OF DPIN3

```fortran
      PROGRAM DPIN3(INPUT,OUTPUT,TAPE60,TAPE61,TAPE5=INPUT,TAPE6=OUTPUT,
     +TAPE89)
      DIMENSION X(202),Y(202),DYDX(202),S(202),TP(202)
      REAL MF,MA,MA1,KFL,KAL,KF,KA
C     THIS PROGRAM COMPUTES THE OFFSETS, SLOPE, AND WETTED AREA OF AN
C     AXISYMMETRIC BODY CONSISTING OF NOSE, PARALLEL MIDDLE BODY, AND
C     TAIL ACCORDING TO GRANVILLE, VSRDC REPORT 3763, 1972.
      READ(5,16) NPTS,NCPTS,INFL
   16 FORMAT(3I10)
      WRITE(6,17) NPTS,NCPTS,INFL
   17 FORMAT(1H1,1X,*NPTS=*,I5,3X,*NCPTS=*,I5, 3X, * INFL = *,I5)
    7 READ(5,1) MF,MA,KFL,KAL,RL,SL,ELD
      IF(EOF(5))8,9
    1 FORMAT(7F 10.6)
    9 WRITE(6,5) MF,MA,KFL,KAL,RL,SL,ELD
    5 FORMAT(//,10X,*INPUT*//,1X,*MF=*,F10.6,2X,*MA=*,F10.6,2X,*KFL=*,
     +F15.6,2X,*KAL=*,F15.6,2X,*RL=*,F10.6,2X,*SL=*,F10.6,2X,*ELD=*,
     +F10.6)
      MA1=1.-MA          $TP(1)=10.*100.*1000.
      DYDX(1)=10.*100.*1000.
      KFL=(D/DX)**3*Y(MF)
      KAL= (D/DX)**3*Y(MA)
      RL=1./((D/DY)**2*X) AT X=0.
      SL= (D/DX)*Y(1)
      KF=2.*ELD*MF**3*KFL
      KA=-2.*ELD*MA1**3*KAL
      R=4.*ELD*FLD*MF*RL
      SP=-2.*ELD*MA1*SL
      S2=SP*SP
      CPF = R/15. - KF/180. + 2./3.
      CDA = S2/105. - KA/420. + 4./7.
      CP = MF*CPF+MA-MF+MA1*CPA
      WRITE (6,4) KF, KA, R, S2, CPF, CPA, CP
    4 FORMAT(/, 1X, * KF = *, F10.6, 2X, *KA = *, F10.6, 2X, *R = *,
     +F10.6, 2X, * S2 = *, F10.6, 2X, *CPF = *, F10.6, 2X, *CPA = *,
     +F10.6, 2X, *CP = *, F10.6)
      WRITE(6,3)
```

76

```
3    FORMAT(//,10X,*OUTPUT*//,4X,*I*,9X,*X*,14X,*Y*,14X,*DYDX*,11X,*S*,
    +14X,*TP*,/)
     DX=.001
     X(1)=0.0          $Y(1)=0.0          $S(1)=0.0
     PI=3.14159
     SM = MA-MF
     AF=0.0            $AA=0.0
     NC1=NCPTS+1
     NC2=NCPTS+2
     NC3=NCPTS+3
     NC4=NCPTS+4
     DO 2 I=2,NPTS
     IF(I.EQ.NC1)DX=.002
     IF(I.EQ.NC2)DX=.003
     IF(I.EQ.NC3)DX=.005
     IF(I.EQ.NC4)DX=.010
     X(I)=X(I-1)+DX
     XX=X(I)
     IF(XX.GE.MF)GO TO13
     XF=XX/MF
     XF1=XF-1.
     Y(I)=SQRT(R**2.*XF*XF1**4+KF*XF*XF*XF1**3/3.+1.-XF1**4*(4.*XF+1.))
    2/(2.*FLD)
     DYDX(I)=(R**2.*(XF1**4+4.*XF*XF1**3)+4.*KF*XF*XF1**4.*(4.*XF+1)+KF*XF*XF1**3/3.+1.*XF1+3.*XF*XF1)/3.
    N-XF1**3*(4.*(4.*XF+1)+4.*XF*XF1**4.*(4.*XF+1)))/(8.*FLD*ELD*(I)*MF)
     IF((DYDX(I).GT.DYDX(I-1)).OR.(DYDX(I).LT.0.)) GO TO 11
     DS=DX*SQRT(1.+DYDX(I)*DYDX(I))
     IF (I.NE.2) GO TO 19
     S(2) = SQRT((X(2)-X(1))*(X(2)-X(1))+((Y(2)-Y(1))*(Y(2)-Y(1))))
     GO TO 27
19   CONTINUE
     S(I)=S(I-1)+DS
27   CONTINUE
     SF = S(I)
     AF=AF+2.*PI*Y(I)*DS
     TP(I)=DYDX(I)/(Y(I)*FLD)
     GO TO
```

77

```
13  CONTINUE
    IF(XX.GE.MA)GO TO 18
    Y(I)=1./(2.*FLD)
    DYDX(I)=0.0
    DS=DX
    S(I)=S(I-1)+DS
    TP(I)=0.0
    GO TO 2
18  CONTINUE
    XA=(1.-XX)/MA1
    XA1=XA-1.
    Y(I)= SQRT(S2*XA*XA*XA1**4+KA*(XA*XA1)**3/3.+1.-XA1**4*(10.*XA*XA
   ++4.*XA+1.))/(2.*FLD)
    DYDX(I)=((S2*XA*XA1**3)*(2.*XA*XA1+4.*XA)+KA*(XA*XA1)**2*(XA1+XA)
    N-XA1**3*(4.*(10.*XA*XA+4.*XA)+XA1*(20.*XA+4.)))/(-R*FLD*FLD*
   +Y(I)*MA1)
    DYDX(NPTS) = DYDX(NPTS-1)
    IF (DYDX(I).GT.0.) GO TO 12
    IF (INFL.NE.0) GO TO 10
    IF (DYDX(I).GT.DYDX(I-1)) GO TO 12
    GO TO 20
10  CONTINUE
    IF((DYDX(I).GT.DYDX(I-1)).AND.(INFL.FO.1))  INFL = 2
    IF((DYDX(I).LT.DYDX(I-1)).AND.(INFL.FO.2))  INFL = 3
    IF((DYDX(I).GT.DYDX(I-1)).AND.(INFL.FO.3))  GO TO 12
20  CONTINUE
    DS=DX*SQRT(1.+DYDX(I)*DYDX(I))
    S(I)=S(I-1)+DS
    SA = S(I)-SF-SM
    AA=AA+2.*PI*Y(I)*DS
    TP(I)=DYDX(I)/(Y(I)*FLD)
2   CONTINUE
    WRITE(5,6)(I,X(I),Y(I),DYDX(I),S(I),TP(I),I=1,NPTS)
6   FORMAT((2X,I3,5F15.5)  )
    WRITE(60)(X(I),Y(I),I=1,NPTS)
    ENDFILE 60
```

```
      WRITE(61) (DYDX(I),I=1,NPTS)
      VL3 = .25*PI*CP/(ELD*ELD)
      WRITE(6,15)VL3
   15 FORMAT(1X,*VOLUME/L3=  *,F15.7)
      AM=PI*(MA-MF)/ELD
      AT=AF+AM+AA
      WRITF(6,25) AF,AM,AA,AT
   25 FORMAT(/1X,*FOREBODY AREA/L2=*;F10.6,3X,*MIDDLE BODY AREA/L2=*,
     VF10.6,3X,*AFTERBODY AREA/L2=*,F10.6,3X,*TOTAL AREA/L2=*,F10.6)
      WRITE(88) VL3,AT, ELD, NPTS, NCPTS
      ST = SF+SM+SA
      WRITE (6,22) SF, SM, SA, ST
   22 FORMAT  (/, 1X, *FOREBODY ARC LENGTH/L = *, F10.6, 3X, *MIDDLEBODY
     + ARC LENGTH/L = *, F10.6, 3X, *AFTERBODY ARC LENGTH/L = *,F10.6,
     +;, 3X, *TOTAL ARC LENGTH/L = *, F10.6)
      GO TO 7
   11 WRITE(6,23)
      STOP
   23 FORMAT(//,1X,*FOREBODY PARAMETERS ARE INADMISSABLE*)
   12 WRITE(6,14)
      STOP
   14 FORMAT(//,1X,*AFTERBODY PARAMETERS ARE INADMISSABLE*)
    8 CONTINUE
      END
```

NPTS= 193 NCPTS= 101 IMPL = 1

INPUT

MF= .259360 MA= .610600 K+L= 24.777000 KAL= -26.472000

RL= .006004 SL= -.299820 FLD= 11.566800

KF = 10.000022 KA = 33.709437 R = .833355 S2 = 6.961273

CPF = .666668 CPA = .557466 CP = .745207

OUTPUT

T	X	Y	DYDX	S	TP
1	0.00000	0.00000	1000000.00000	0.00000	1000000.00000
2	.00100	.00347	1.73263	.00361	43.22714
3	.00200	.00490	1.22515	.00519	21.61354
4	.00300	.00600	1.00033	.00660	14.40897
5	.00400	.00693	.86630	.00793	10.80666
6	.00500	.00775	.77483	.00919	8.64523
7	.00600	.00849	.70731	.01042	7.20425
8	.00700	.00917	.65483	.01161	6.17494
9	.00800	.00980	.61251	.01278	5.40292
10	.00900	.01040	.57746	.01394	4.80242
11	.01000	.01096	.54780	.01508	4.32198
12	.01100	.01149	.52227	.01621	3.92886
13	.01200	.01200	.50000	.01732	3.60122
14	.01300	.01249	.48034	.01843	3.32395
15	.01400	.01296	.46282	.01954	3.08625
16	.01500	.01342	.44707	.02063	2.88020
17	.01600	.01386	.43281	.02172	2.69987
18	.01700	.01429	.41983	.02281	2.54072
19	.01800	.01470	.40793	.02389	2.39922

20	.01900	.01510	.39697	.02496	2.27257
21	.02000	.01549	.38684	.02603	2.15855
22	.02100	.01588	.37743	.02710	2.05536
23	.02200	.01625	.36866	.02817	1.96150
24	.02300	.01661	.36045	.02923	1.87577
25	.02400	.01697	.35276	.03029	1.79715
26	.02500	.01732	.34552	.03135	1.72478
27	.02600	.01766	.33869	.03241	1.65794
28	.02700	.01800	.33223	.03346	1.59602
29	.02800	.01833	.32611	.03451	1.53848
30	.02900	.01865	.32030	.03556	1.48488
31	.03000	.01897	.31477	.03661	1.43481
32	.03100	.01928	.30950	.03766	1.38794
33	.03200	.01959	.30446	.03870	1.34396
34	.03300	.01989	.29964		1.30262
35	.03400	.02018	.29503		1.26367
36	.03500	.02048	.29060		1.22691
37	.03600	.02077	.28635	.04287	1.19216
38	.03700	.02105	.28226	.04391	1.15925
39	.03800	.02133	.27832	.04495	1.12804
40	.03900	.02161	.27452	.04598	1.09840
41	.04000	.02188	.27084	.04702	1.07021
42	.04100	.02215	.26730	.04805	1.04336
43	.04200	.02241	.26386	.04909	1.01775
44	.04300	.02268	.26054	.05012	.99330
45	.04400	.02294	.25731	.05116	.96993
46	.04500	.02319	.25418	.05219	.94757
47	.04600	.02344	.25114	.05322	.92615
48	.04700	.02369	.24819	.05425	.90560
49	.04800	.02394	.24531	.05528	.88588
50	.04900	.02418	.24251	.05631	.86694
51	.05000	.02443	.23978	.05734	.84872
52	.05100	.02466	.23712	.05836	.83118
53	.05200	.02490	.23452	.05939	.81429
54	.05300	.02513	.23198	.06042	.79800
55	.05400	.02536	.22950	.06144	.78229
56	.05500	.02559	.22708	.06247	.76711

57	.05600	.02542	.22470	.06349	.75245
58	.05700	.02604	.22238	.06452	.73827
59	.05800	.02626	.22010	.06554	.72456
60	.05900	.02648	.21787	.06656	.71127
61	.06000	.02670	.21567	.06759	.69840
62	.06100	.02691	.21352	.06861	.68593
63	.06200	.02713	.21141	.06963	.67382
64	.06300	.02734	.20934	.07065	.66207
65	.06400	.02754	.20730	.07168	.65066
66	.06500	.02775	.20529	.07270	.63958
67	.06600	.02795	.20332	.07372	.62880
68	.06700	.02816	.20137	.07474	.61831
69	.06800	.02836	.19946	.07576	.60811
70	.06900	.02856	.19757	.07678	.59817
71	.07000	.02875	.19571	.07779	.58849
72	.07100	.02895	.19388	.07881	.57905
73	.07200	.02914	.19207	.07983	.56985
74	.07300	.02933	.19029	.08085	.56088
75	.07400	.02952	.18853	.08187	.55212
76	.07500	.02971	.18678	.08288	.54356
77	.07600	.02989	.18506	.08390	.53521
78	.07700	.03008	.18336	.08492	.52704
79	.07800	.03026	.18168	.08593	.51906
80	.07900	.03044	.18002	.08695	.51126
81	.08000	.03062	.17838	.08797	.50362
82	.08100	.03080	.17675	.08898	.49615
83	.08200	.03097	.17514	.09000	.48884
84	.08300	.03115	.17354	.09101	.48167
85	.08400	.03132	.17196	.09203	.47465
86	.08500	.03149	.17040	.09304	.46777
87	.08600	.03166	.16884	.09406	.46103
88	.08700	.03183	.16731	.09507	.45442
89	.08800	.03200	.16578	.09608	.44793
90	.08900	.03216	.16427	.09710	.44156
91	.09000	.03233	.16277	.09811	.43532
92	.09100	.03249	.16128	.09912	.42918
93	.09200	.03265	.15980	.10014	.42315

94	.09300	.03291	.15833	.10115	.41724
95	.09400	.03296	.15687	.10216	.41142
96	.09500	.03312	.15543	.10317	.40570
97	.09600	.03328	.15399	.10418	.40008
98	.09700	.03343	.15256	.10520	.39455
99	.09800	.03358	.15114	.10621	.38911
100	.09900	.03373	.14973	.10722	.38376
101	.10000	.03388	.14833	.10823	.37850
102	.10200	.03417	.14555	.11025	.36821
103	.10500	.03460	.14143	.11328	.35334
104	.11000	.03529	.13471	.11832	.32996
105	.12000	.03658	.12168	.12840	.28761
106	.13000	.03773	.10910	.13846	.25000
107	.14000	.03876	.09690	.14250	.21614
108	.15000	.03967	.08503	.15854	.18532
109	.16000	.04046	.07351	.16857	.15707
110	.17000	.04114	.06236	.17859	.13105
111	.18000	.04171	.05166	.18860	.10707
112	.19000	.04218	.04149	.19861	.08505
113	.20000	.04254	.03198	.20861	.06499
114	.21000	.04282	.02329	.21862	.04703
115	.22000	.04301	.01561	.22862	.03137
116	.23000	.04313	.00916	.23862	.01835
117	.24000	.04320	.00420	.24862	.00840
118	.25000	.04322	.00103	.25862	.00207
119	.26000	.04323	0.00000	.26862	0.00000
120	.27000	.04323	0.00000	.27862	0.00000
121	.28000	.04323	0.00000	.28862	0.00000
122	.29000	.04323	0.00000	.29862	0.00000
123	.30000	.04323	0.00000	.30862	0.00000
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125	.32000	.04323	0.00000	.32862	0.00000
126	.33000	.04323	0.00000	.33862	0.00000
127	.34000	.04323	0.00000	.34862	0.00000
128	.35000	.04323	0.00000	.35862	0.00000
129	.36000	.04323	0.00000	.36862	0.00000
130	.37000	.04323	0.00000	.37862	0.00000

131	.38000	.04323	0.00000	.38862	0.00000
132	.39000	.04323	0.00000	.39862	0.00000
133	.40000	.04323	0.00000	.40862	0.00000
134	.41000	.04323	0.00000	.41862	0.00000
135	.42000	.04323	0.00000	.42862	0.00000
136	.43000	.04323	0.00000	.43862	0.00000
137	.44000	.04323	0.00000	.44862	0.00000
138	.45000	.04323	0.00000	.45862	0.00000
139	.46000	.04323	0.00000	.46862	0.00000
140	.47000	.04323	0.00000	.47862	0.00000
141	.48000	.04323	0.00000	.48862	0.00000
142	.49000	.04323	0.00000	.49862	0.00000
143	.50000	.04323	0.00000	.50862	0.00000
144	.51000	.04323	0.00000	.51862	0.00000
145	.52000	.04323	0.00000	.52862	0.00000
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147	.54000	.04323	0.00000	.54862	0.00000
148	.55000	.04323	0.00000	.55862	0.00000
149	.56000	.04323	0.00000	.56862	0.00000
150	.57000	.04323	0.00000	.57862	0.00000
151	.58000	.04323	0.00000	.58862	0.00000
152	.59000	.04323	0.00000	.59862	0.00000
153	.60000	.04323	0.00000	.60862	0.00000
154	.61000	.04323	0.00000	.61862	0.00000
155	.62000	.04323	0.00000	.62862	0.00000
156	.63000	.04322	-.00132	.63862	-.00263
157	.64000	.04319	-.00467	.64862	-.00934
158	.65000	.04312	-.00954	.65862	-.01913
159	.66000	.04300	-.01551	.66862	-.03119
160	.67000	.04281	-.02222	.67862	-.04487
161	.68000	.04255	-.02938	.68863	-.05968
162	.69000	.04222	-.03674	.69863	-.07523
163	.70000	.04182	-.04413	.70864	-.09124
164	.71000	.04134	-.05140	.71866	-.10750
165	.72000	.04079	-.05845	.72867	-.12387
166	.73000	.04017	-.06519	.73870	-.14028
167	.74000	.03949	-.07157	.74872	-.15669

168	.75000	.03874	.75875	-.07758	-.17311
169	.76000	.03794	.76879	-.08320	-.18959
170	.77000	.03708	.77882	-.08845	-.20622
171	.78000	.03617	.78887	-.09336	-.22315
172	.79000	.03521	.79892	-.09799	-.24057
173	.80000	.03421	.80897	-.10239	-.25874
174	.81000	.03317	.81902	-.10665	-.27799
175	.82000	.03208	.82909	-.11084	-.29873
176	.83000	.03095	.83915	-.11508	-.32147
177	.84000	.02978	.84922	-.11947	-.34688
178	.85000	.02856	.85930	-.12412	-.37575
179	.86000	.02729	.86938	-.12916	-.40913
180	.87000	.02597	.87947	-.13470	-.44833
181	.88000	.02460	.88957	-.14086	-.49509
182	.89000	.02315	.89968	-.14776	-.55171
183	.90000	.02164	.90980	-.15552	-.62136
184	.91000	.02004	.91993	-.16425	-.70855
185	.92000	.01835	.93009	-.17404	-.81997
186	.93000	.01656	.94025	-.18500	-.96602
187	.94000	.01465	.95045	-.19719	-1.16397
188	.95000	.01261	.96067	-.21070	-1.44478
189	.96000	.01043	.97092	-.22559	-1.87027
190	.97000	.00809	.98121	-.24190	-2.58459
191	.98000	.00558	.99154	-.25969	-4.02005
192	.99000	.00289	1.00192	-.27899	-8.33800
193	1.00000	.00000	1.01730	-.27899	-3.309730.03141

VOLUME/L3= .0043766

FOREBODY AREA/L2= .053528   MIDDLE BODY AREA/L2= .097843

AFTERBODY AREA/L2= .072787   TOTAL AREA/L2= .224157

FOREBODY ARC LENGTH/L = .259619   MIDDLE-BODY ARC LENGTH/L = .360240

AFTERBODY ARC LENGTH/L = .393443

TOTAL ARC LENGTH/L = 1.012362

APPENDIX D

DESCRIPTION OF DA50 AND DESCRIPTION, GLOSSARY, LISTING, AND SAMPLE RUN OF DPOUT

DESCRIPTION OF DA50

DA50 is the DTNSRDC designation of the Douglas-Neumann potential-flow program for axisymmetric bodies.[12] This program represents bodies by ensembles of flat quadrilaterals, on each of which there is an (initially) unknown constant source strength. A Fredholm integral equation of the second kind for the velocity potential results from requiring the flow to be tangent to the body surface. (This is Equation (2.5) in Hess and Smith.[12]) Since there are only a finite number of panels and sources which induce the velocity potential, the integral equation is replaced by a system of linear algebraic equations, of number equal to the number of quadrilaterals, each one of which involves all of the source strengths. Thus solution of the algebraic equations involves inversions of square matrices with the length of each side equal to the number of quadrilaterals. After the source strengths are determined, the velocity potential and velocity components and pressure anywhere in the flow field can easily be found in terms of the source strengths.

In the axisymmetric case, the quadrilaterals become frustums of cones, with axes along the body's axis of symmetry. DA50 is so long that it is divided into six overlay links. LINK 1 sets up the panels and algebraic equations for the source strengths. LINK 2, LINK 3, LINK 4 and LINK 5 provide options for solving the algebraic equations. LINK 2, which uses the Seidel iteration, is the only one which has been used in this project. (LINK 3 solves the algebraic equations by a direct method; LINK 4 prepares a tape for LINK 5 which solves the matrices by successive orthogonalization.) LINK 6 computes the desired velocity potential, velocity components, and pressure coefficients due to the source strengths and prints them. Thus when DA50 is entered again to compute the revised velocity distribution due to the effect of displacement thickness, only LINK 6 is used; no repetition of the time-consuming inversion is needed.

DESCRIPTION OF DPOUT

This program uses the results of DPIN and DA50 together with viscous-flow theory presented elsewhere in this report and in References 1-4 to compute the boundary layer on a body of revolution. The boundary layer is laminar at the nose, undergoes transition to turbulence at some point downstream of the nose if the overall Reynolds number R_L is sufficiently large, continues as a turbulent boundary layer to the tail, and leaves the body as a turbulent wake. However, if R_L is sufficiently small that laminar separation occurs on the forebody, transition can be forced to occur at the laminary-separation point. DPOUT includes four different methods of controlling transition:

1. The method of Granville[2] is generalized to lower values of $\frac{D_o}{y} \frac{dy}{dx}$, where D_o is the maximum diameter, and to flows with high background turbulence. This includes three subcases.

2. The method of Granville[1] as used by Smith.[3]

3. Transition can be forced to occur at a designated point, either because it has been observed to occur there in an experiment or because a trip has been placed there. If a trip is used, DPOUT includes an option increase in R_θ (and ultimately in total drag) to account for the parasitic drag of the trip. Designation of a transition point does not prevent transition from occurring upstream of it if this is predicted by one of the other three options which has been chosen.

4. If laminar separation occurs upstream of the transition point determined by one of the other three methods, the user has the option of defining the separation point as the transition point. Thus when this option is selected, it is assumed that a separated laminary boundary layer immediately reattaches as a turbulent boundary layer.

The program also includes the option of setting the velocity and wall radius at constant values and thus calculating the flat-plate drag as a check. In this case the body is effectively replaced by a circular cylinder with a very thin wall and a radius equal to the maximum body radius, and the drag on the inner surface of the wall is not included.

Input variables to DPOUT include, aside from the data on tape written by DPIN and DA50, the following:

ICONTRL   This integer is a control variable which should be zero the first time the boundary layer is calculated for a given body and overall length Reynolds number R_L, if a recomputation is to be made which includes the augmented hydrodynamic source strength to represent the effect of the displacement thickness. If no recomputation is to be made, set ICONTRL = 1. If the run is to use the recomputed data (i.e. it is not an initial run to obtain DELSIG), also set ICONTRL = 1.

I53   This integer is a control variable which should be 1 if and only if it is desired to use the transition criterion of Reference 1 instead of that of Reference 2.

ITRIP   This integer is a control variable which should be 1 if and only if it is desired that transition take place at XTRIP if it has not occurred upstream of it.

XTRIP   This floating-point number is the location where transition is forced, expressed as axial distance from the nose divided by total length. It must be input even if ITRIP is unequal to 1.

IDRTH   This integer is a control variable which should be 1 if and only if it is desired that at the point where transition is forced, an increment be added to the momentum-thickness Reynolds number to represent the added drag due to a sand strip. It must be input even if ITRIP is unequal to 1.

IFP   This integer is a control variable which should be 1 if and only if it is desired to replace the body shape by a circular cylinder with its surface parallel to the undisturbed flow and to replace the computed velocity by the undisturbed-flow speed. This provides flat-plate results which give a useful check on the computations.

ITLS   This integer is a control variable which should be 1 if and only if it is desired to force transition to take place at the laminar separation point in cases where the Reynolds number is so low that transition would not otherwise occur until downstream of the laminar separation point. Thus it is assumed that a separated laminar boundary layer immediately reattaches as a turbulent boundary layer.

RL   This floating-point number is the Reynolds number based on body length and velocity of the undisturbed flow.

J   This integer is a control variable which is 1 if and only if, when using the transition criterion of Reference 2, it is desired to use the low-background-turbulence correlation curve. It should be input even if I53 is 1.

L   This integer is a control variable which is 1 if and only if, when the transition criterion of Reference 2 is used with J = 1 and TP is sufficiently large, it is desired to use as the transition criterion a constant difference of 639 between RTHT and RTHN. Although it is meaningless with J not equal to 1 or if I53 = 1, it should be input in these cases.

The program is able to treat the same body with a number of different values of RL, J, and L because after execution for one set of values, it returns and reads the next.

As the program reads NPTS, NCPTS, VL3, AT, I53, ITRIP, XTRIP, IDRTH, IFP, and ITLS, it writes them out. It also reads the body-shape description calculated by DPIN and the velocity distribution calculated by DA50. DA50 gives the tangential velocity at the center of the integration steps, and DPOUT uses velocity at the ends of the steps, so the latter is found by linear interpolation. Linear interpolation of velocity at 95 percent of the axial length is also used over the last 5 percent of the body. The x-derivative of velocity is also needed by the program, and this is calculated by a numerical-differentiation subroutine, DGT3, which is described in the IBM reference manual.[11] If IFP is 1, Y(I) is replaced by the maximum radius and U(I) by the speed of the undisturbed flow. Next I, X, Y, U, and DUDX are written out for points on the body. RL, J, and L are read for the case and written out. Various quantities used in computing the boundary layer are initialized and the laminar-boundary-layer calculations are begun by entering a DO loop in which the neutral-stability point is located if RL is large enough for there to be such a point. The methods by which the laminar boundary layer and the neutral-stability point are calculated are described elsewhere. If no neutral-stability point is found, a message to the effect that RL is too small is printed out and the program goes to the next RL, J, and L. If the neutral-stability point is found, the program writes out I, X, Y, U, RTH, etc. at that point, denoting them with N as the last letter, and continues the

90

laminar-boundary-layer calculations by entering a new DO loop in which the transition point is located by the method of Reference 2 or, if I53 is 1, by the method of Reference 1 as long as RL is large enough for there to be such a point. If RL is not large enough, the program prints out a message to that effect and goes to the next RL, J, and K. Details of the two transition-prediction methods have been summarized previously. Both upstream and downstream of the neutral-stability point the shear stress is calculated according to the Blasius flat-plate formula, and if ITRIP is 1, transition takes place immediately if X passes XTRIP. Also, both upstream and downstream of the neutral stability point a check for laminar separation is made. If laminar separation is encountered, the program prints out a message to that effect and goes to the next RL, J, and K unless ITLS is 1, in which case transition takes place at the laminar-separation point. I, X, Y, U, PGP, and RTH are written out at each point on the laminar boundary layer.

At the transition point, I, X, Y, U, RTH, etc. are again printed out, denoted by T as the last letter, and the turbulent-boundary-layer calculations are begun by entering a new DO loop. H at transition (denoted by HT) is given by Equation (15). The method by which the turbulent boundary layer is calculated appears elsewhere in this report and has been given in detail by Granville.[4] The calculations begin at the first point downstream of the transition point through which it is assumed that TH, and hence RTH, are continuous. Then HT is found by using Equation (15) and SG is found by using Equation (16). The method by which the transcendental Equation (16) is solved for SG with H and RTH known consists of using H and RTH to evaluate its right-hand side (denoted by FR). As a first try, SG = 11.0 is used. If the left-hand side (denoted by FS) is less than FR, SG is increased by 100 and FS is reevaluated. If FS is now no less than FR, SG is decreased in steps of 10.0 until it is less than FR. In the same way, if the FS based on SG = 11.0 had been no less than FR, SG would be decreased by steps of 10.0 until FS were less than FR. The process is continued in this way; SG increases in steps of 100, decreases in steps of 10, increases in

steps of 1, etc., with comparisons of FS and FR made at each stage, until SG has been found to an accuracy of 0.001. Next Equations (17)- (34) are solved so that the right-hand sides of Equations (35) and (36) can be evaluated. Equations (35)-(38) are solved by using a two-stage predictor-corrector technique, governed by a control variable K which is 1 in the first ("predictor") stage and 2 is the second ("corrector") stage. With K = 1 the coefficients and right-hand sides of Equations (35) through (38) are evaluated by using quantities at the left-hand ends of the integration steps. The coefficients and increments are denoted by DOML2P, DPSIL2P, A1P, B1P, C1P, A2P, B2P, C2P, C3P, C4P, DTHP, and DHP. After they have been evaluated and OML2, PSIL2, TH, and H incremented by DOML2P, DPSIL2P, DTHP, and DHP, the program changes K to 2 and returns to the point where SG is found from Equation (16) and repeats the calculations. During this stage, the right-hand sides of Equations (35)-(38) are evaluated by using values of OML2, PSIL2, TH, and H which were estimated at the "predictor" stage. The revised coefficients and increments are denoted by DOML2C, DPSIL2C, A1C, B1C, C1C, A2C, B2C, C2C, C3C, C4C, DTHC, and DHC. The final increments in OML2, PSIL2, TH and H over the values at the beginning of the integration step are 0.5 * (DOML2P + DOML2C), 0.5 * (DPSIL2P + DPSIL2C), 0.5 * (DTHP + DTHC), and 0.5 * (DHP + DHC). The shear-stress coefficient CF is calculated by using Equation (4), with C_τ now equal to $2/SG^2$. After all the calculations have been made at this point on the turbulent boundary layer, the values of I, OML2, PSIL2, ELSL2, TH, H, SG, $\log_e$ (RTH), and CF are written out. Next the program returns to the beginning of the DO loop, sets K back to 1, and repeats the calculations on the second integration step downstream of transition. The only difference is that OML2 and PSIL2 at the beginning of the new step are now known and Equations (32) and (33) are not used. The process is continued until the DO loop is completed and quantities have been computed at each point along the turbulent boundary layer. However, a different computation method is used over the last five points; OML2, PSIL2, TH, and H are computed by linear extrapolation of the values at the two previous points.

After completion of the DO loop for the turbulent boundary layer, DELSIG is computed at each point along the body if ICONTRL is not 1. DELSIG is computed by using Equation (6) except on the last five points, where linear interpolation from the two previous points is used.

The values of quantities at the tail, namely, I, HE, THE, OML2E, PSIL2E, ELSL2E, SHE (defined by SHE $= \frac{ESL2E}{OML2E}$), and UE are written out. OML2D is computed by using Equations (48), (49), and (50). The drag coefficients based on (volume)$^{2/3}$ and wetted area as reference areas are computed by using Equation (47) and written out. If ICONTRL is not 1, values of DELSIG at the centers at the integration steps are computed by using linear interpolation from the end points of the steps. These are stored on tape for use during the reexecution of last part of DA50 to represent the effect of displacement thickness.

DPOUT - GLOSSARY

The following glossary of variables used in DPOUT is arranged alphabetically by FORTRAN variable name.

FORTRAN Variable Name	Variable	Definition
ALOGPGF	anti $\log_{10}$ (PGF)	Inverse of $\log_{10}$ (PGF)
ALRTH	anti $\log_e$ (RTH)	Inverse of $\log_e$ (RTH)
AT	$A^{(t)}$	Total wetted area
A1C	$A_1^{(c)}$	Element in matrix for DHC and DTHC
A1P	$A_1^{(p)}$	Element in matrix for DHP and DTHP
A2C	$A_2^{(c)}$	Element in matrix for DHC and DTHC
A2P	$A_2^{(p)}$	Element in matrix for DHP and DTHP

93

FORTRAN Variable Name	Variable	Definition
B	β	$\displaystyle\int_{0}^{x/L} U^5 (x'/L)\, y^2 (x'/L)\, [\sec \alpha\, (x'/L)]\, dx'/L$
BE	$\beta^{(e)}$	$\left(\dfrac{G + 1.6}{6.1}\right)^2 - 1.81$
BLAM	$\overline{\lambda}$	$\dfrac{4}{45} - \dfrac{1}{5}\; \dfrac{(R_\theta^2/R_L\, y^2/U)_t - (R_\theta^2/R_L\, y^2/U)_n}{\displaystyle\int_{x_n/L}^{x_t/L} y^2 (x'/L)\, [\sec \alpha\, (x'/L)]\, d\, x'/L}$
BO	β_o	β evaluated at previous integration step
B1C	$B_1^{(c)}$	Element in matrix for DHC and DTHC
B1P	$B_1^{(p)}$	Element in matrix for DHP and DTHP
B2C	$B_2^{(c)}$	Element in matrix for DHC and DTHC
B2P	$B_2^{(p)}$	Element in matrix for DHP and DTHP
CD	C_D	Drag coefficient based on $(\text{volume})^{2/3}$
CF	C_f	$\displaystyle\int_{0}^{x/L} C_\tau (x'/L)\, d\, (x'/L)$ where $C_\tau (x/L)$ is the local skin-friction coefficient and $C_\tau (x/L)\, [\cos \alpha\, (x/L]$ is its axial component
CFN	$C_f^{(n)}$	C_f at neutral stability

FORTRAN Variable Name	Variable	Definition
CFT	$C_f^{(t)}$	C_f at transition
CS	C_s	Drag coefficient based on wetted area
C1C	$C_1^{(c)}$	Term used in calculating $C_3^{(c)}$
C1P	$C_1^{(p)}$	Term used in calculating $C_3^{(p)}$
C2C	$C_2^{(c)}$	Term used in calculating $C_4^{(c)}$
C2P	$C_2^{(p)}$	Term used in calculating $C_4^{(p)}$
C3C	$C_3^{(c)}$	Element in matrix for DHC and DTHC
C3P	$C_3^{(p)}$	Element in matrix for DHP and DTHP
C4C	$C_4^{(c)}$	Element in matrix for DHC and DTHC
C4P	$C_4^{(p)}$	Element in matrix for DHP and DTHP
D	D	$$\int_{x_n/L}^{x/L} [y\,(x'/L)]^2\,[\sec\,\alpha\,(x'/L)]\,d\,x/L$$ (evaluated for $x_n \leq x \leq x_T$)
DCOS	$d \cos \alpha$	Increment on $\cos \alpha\,(x/L)$ over an integration step
DDELSIG		DELSIG evaluated at center of integration step by linear interpolation; dimensioned to be a function of I
DELDX	$\dfrac{d\text{ELSL2}}{dx}$	Derivative of ELSL2 with respect to x; dimensioned to be a function of I

FORTRAN Variable Name	Variable	Definition
DELSIG	δ SIG	Increment in source strength SIG (of DA50) which represents the effect of displacement thickness; dimensioned to be a function of I
DHC	$\delta H^{(c)}$	Increment in H over an integration step, evaluated at corrector stage of predictor-corrector method
DHDH	$\dfrac{\partial HD}{\partial H}$	Derivative of HD with respect to H
DHDR	$\dfrac{\partial HD}{\partial (\log_e RTH)}$	Derivative of HD with respect to $\log_e$ RTH
DHP	$\delta H^{(p)}$	Increment in H over an integration step, evaluated at predictor stage of predictor-corrector method
DHPH	$\dfrac{\partial HP}{\partial H}$	Derivative of HP with respect to H
DHPR	$\dfrac{\partial HP}{\partial (\log_e RTH)}$	Derivative of HP with respect to $\log_e$ RTH
DHR	$\dfrac{\partial HT}{\partial (\log_e RTH)}$	Derivative of HTL with respect to $\log_e$ RTH
DHTH	$\dfrac{\partial HT}{\partial H}$	Derivative of HTL with respect to H
DOML2C	$\delta OML2^{(c)}$	Increment in OML2 over an integration step, evaluated at corrector stage of predictor-corrector method
DOML2P	$\delta OML2^{(p)}$	Increment in OML2 over an integration step, evaluated at predictor stage of predictor-corrector method
DPSIL2C	$\delta PSIL2^{(c)}$	Increment in PSIL2 over an integration step, evaluated at corrector stage of predictor-corrector method

FORTRAN Variable Name	Variable	Definition
DPSIL2P	δ PSIL2$^{(p)}$	Increment in PSIL2 over an integration step, evaluated at predictor stage of predictor-corrector method
DRTH	δ RTH	Increment in RTH due to the presence of a sand strip used as a transition trip
DSH	$\dfrac{1}{SG}\dfrac{\partial\, SG}{\partial\, H}$	1/SG times derivative of SG with respect to H
DSR	$\dfrac{1}{SG}\dfrac{\partial\, SG}{\partial\,(\log_e RTH)}$	1/SG times derivative of SG with respect to $\log_e$ RTH
DTHC	δ TH$^{(c)}$	Increment in TH over an integration step, evaluated at corrector stage of predictor-corrector method
DTHP	δ TH$^{(p)}$	Increment in TH over an integration step, evaluated at predictor stage of predictor-corrector method
DU	δ U	Increment in U over an integration step
DUDX	$\dfrac{dU}{dX}$	Derivative of U with respect to X; dimensioned to be a function of I
DX	dX	Length of an integration step
DY	δ Y	Increment in Y over an integration step
DYDX	$\dfrac{dY}{dX}$	Derivative of Y with respect to X; dimensioned to be a function of I
DO	D_o	Value of D at previous integration step
E	E	Entrainment factor, equal to EC/SG^2
EC	$\hat{E}$	Reduced entrainment factor
EE	e	Base of natural logarithms

FORTRAN Variable Name	Variable	Definition
ELD	L/MAX. DIAMETER	Ratio of body length to maximum diameter; here the body length is one so it is the inverse of the diameter
ELSL2	$\Lambda*/L^2$	Displacement area divided by square of body length
ELSL2E	$\text{ELSL2}^{(e)}$	ELSL2 evaluated at tail
F	F	Integrand of B
FD	FD	Integrand of D
FDO	FD	Value of FD at previous integration step
FR	$F^{(r)}$	Function of $\log_e$ RTH and H used to compute SG
FRTHN	$F(\text{RTH}^{(n)})$	$\text{RTH2RL}^{(n)} \dfrac{\left(Y^{(n)}\right)^2}{U^{(n)}}$
FS	$F^{(s)}$	Function of SG and H used in computing SG by taking trial values of SG and comparing FS with FR
FO	F_o	Value of F at previous integration step
G	G	Rotta shape parameter, equal to $\text{SG} \dfrac{H-1}{H}$
H	H	Shape parameter, equal to $\delta*/\theta$
HD	H_Δ	Quadratic displacement-shape parameter
HE	$H^{(e)}$	H evaluated at tail
HP	H_ϕ	Quadratic momentum-shape parameter
HT	$H^{(t)}$	H evaluated at transition point

FORTRAN Variable Name	Variable	Definition
HTL	$\tilde{H}$	Entrainment-shape parameter
I	i	Integer which increases from 1 at the nose to NCPTS at the point where the step size begins increasing, hence to NPTS at the tail
IBID	IBID	Dummy variable for I, used in DO loop when DELSIG is computed in the case where RL is so small that the point of neutral stability is never reached on the body
ICAN	ICAN	Dummy variable for I, used in DO loop when DELSIG is computed in the case where transition to turbulence occurs on the body
ICONTRL	ICONTRL	Control variable which is 1 when the execution of DPOUT uses the velocity distribution corresponding to the hydrodynamic source strength which includes the effect of displacement thickness
IDRTH	$I^{(dRTH)}$	Control variable which is meaningful only if ITRIP is 1; IDRTH is 1 if and only if it is desired to increment RTH to represent added drag due to the effect of a sand strip which stimulates transition
IER	IER	Error parameter used in subroutine DGT3
IFP	$I^{(FP)}$	Control variable which is 1 if and only if it is desired to obtain flat-plate results by setting U = 1.0 and Y = (maximum diameter/2)
IN	$I^{(n)}$	I at neutral stability point
IN1	$I^{(n)} + 1$	

FORTRAN Variable Name	Variable	Definition
IQUIT	IQUIT	Control variable which ensures termination and procession to the next R_L in a case where laminar separation occurs for an R_L
IT	$I^{(t)}$	I at transition
ITLS	$I^{(tls)}$	Control variable which is 1 if and only if it is desired that if laminar separation occurs at a point, then that point will be defined as the transition point
ITRIP	$I^{(trip)}$	Control variable which is 1 if and only if it is desired to force transition at a point (x = XTRIP) if it has not occurred upstream of that point
ITRY	ITRY	Dummy variable for I, used in the DO loop where DELSIG is computed in the case where RL is so small that the transition point is not reached
IT1	$I^{(t)} + 1$	I at the first point downstream of the transition point
I53	$I^{(53)}$	Control variable which should be set equal to 1 if and only if it is desired to use the transition criterion of Reference 1 rather than that of Reference 2
J	J	Control variable, meaningful only when the transition criterion of Reference 2 is being used; J = 1 gives the correlation curve for low-background turbulence and J = 2 gives the correlation curve for high-background turbulence
K	K	Control variable for predictor-corrector method of step-by-step integration of the turbulent boundary layer; K is 1 in the predictor stage and 2 in the corrector stage

FORTRAN Variable Name	Variable	Definition
L	L	Control variable, meaningful only when the transition criterion of Reference 2 is being used with $J = 1$; $L = 1$ gives a flat line for RTHT-RTHN at large values of TP and $L \neq 1$ gives a sloping line for it
NCPTS	$N^{(c)}$	Number of the point downstream of which the point spacing begins to increase
NC1	NCPTS + 1	
NC2	NCPTS + 2	
NC3	NCPTS + 3	
NC4	NCPTS + 4	
NM1	NPTS - 1	
NM2	NPTS - 2	
NM3	NPTS - 3	
NM4	NPTS - 4	
NM5	NPTS - 5	
NM6	NPTS - 6	
NPTS	N	Total number of points
NP1	NPTS + 1	
OML2	Ω/L^2	Momentum area divided by square of total length
OML2D	$OML2^{(d)}$	OML2 far downstream of the body
OML2E	$OML2^{(e)}$	OML2 at tail
OML2T	$OML2^{(t)}$	OML2 at the transition point; a function of PGP used to find the neutral-stability point

FORTRAN Variable Name	Variable	Definition
PGP		A function, equal to $\dfrac{RTH2RL * DUDX}{SECA * U * U}$, used to find the neutral stability point and, if it occurs, laminar separation; PGP is also equal to $\dfrac{\theta^2}{\nu}\dfrac{dU}{ds}$, where θ, ν and $\dfrac{dU}{ds}$ are dimensional
PGPN	$PGP^{(n)}$	PGP at the neutral-stability point
PI	π	Ratio of circumference of a circle to its diameter
PSIL2	ψ/L^2	Entrainment area divided by square of length
PSIL2E	$PSIL2^{(e)}$	PSIL2 at tail
RL	R_L	Reynolds number based on total length L and U_∞, the velocity far upstream
RS	R_s	Reynolds number based on distances along the body and U_∞, the velocity far upstream
RTH	R_θ	Reynolds number based on momentum thickness and local velocity outside the boundary layer; RTH is equal to both $\dfrac{\theta U}{\nu}$, where θ, U, and ν are dimensional, and to TH * U * RL
RTHN	$RTH^{(n)}$	RTH at neutral-stability point
RTHT	$RTH^{(t)}$	RTH at transition point
RTH2RL	RTH^2/R_L	R_θ^2/R_L
SECA	$\sec \alpha$ (I)	Secant of α, evaluated at I; α is the angle between the tangent to the body surface and the x-axis

FORTRAN Variable Name	Variable	Definition
SEC1	SECA $(I + 1)$	Secant of α, evaluated at $I + 1$; α is the angle between the tangent to the body surface and the x-axis
SG	σ	$SG = \sqrt{2/C_\tau}$, where C_τ is the local shear-stress coefficient
SHE	$SH^{(e)}$	SH at tail; $SHE = \dfrac{ELSL2E}{OML2E}$
SKIP	SKIP	Variable used to control point at which reading of a tape begins
TF	TF	A function of TP, used in the transition criterion of Reference 2, according to which transition occurs at that point downstream of neutral stability where RTH − RTHN first exceeds TF; there are three alternative functional relationships between TF and TP, depending on the values of J and L
TFR	TFR	TF + RTHN
TFT	$TF^{(t)}$	TF at transition point
TF53	$TF^{(53)}$	$2 * ELD * (Y(I) * RTH - YN * RTHN)$; according to the transition criterion of Reference 1, transition occurs where TF53 first exceeds TP53
TH	θ/L	Momentum thickness divided by overall length
THE	$TH^{(e)}$	TH at tail
THT	$TH^{(t)}$	TH at transition point
TP	TP	A function of body geometry, defined as $TP = \dfrac{L}{Y(I) * ELD} * \dfrac{dY(I)}{dX}$
TPT	$TP^{(t)}$	TP at transition point

FORTRAN Variable Name	Variable	Definition
TP53	$TP^{(53)}$	Function used to predict transition described in Reference 1 and defined as $TP53 = 450 + 400e^{BLAM}$
U	U/U_∞	Velocity in flow field immediately outside boundary layer, divided by velocity far upstream; dimensioned to be a function of I
UE	$U^{(e)}$	U at tail
UN	$U^{(n)}$	U at neutral-stability point
UT	$U^{(t)}$	U at transition point
UU	UU	U evaluated at center of integration step by linear interpolation; dimensioned to be a function of I
VL3	V/L^3	Body volume divided by cube of total length
X	x/L	Axial coordinate divided by total length; dimensioned to be a function of I
XN	$X^{(n)}$	X at neutral-stability point
XT	$X^{(t)}$	X at transition point
XTRIP	$X^{(trip)}$	If transition has not occurred upstream of XTRIP and if ITRIP is set equal to 1, transition is forced to occur at XTRIP
XX		Axial coordinate, identical to X except that it is not dimensioned as a function of I
Y		Body radius divided by total length; dimensioned to be a function of I
YN	$Y^{(n)}$	Y at neutral-stability point
YT	$Y^{(t)}$	Y at transition point

```
      PROGRAM DPOUT(INPUT,OUTPUT,OUTPUT,TAPE61,TAPE60,TAPE20,TAPE5=INPUT,TAPE6=
     6OUTPUT,TAPE9R,TAPE8R,TAPE87)
      DIMENSION U(200),DYDX(200),X(200),Y(200),DUDX(200),DELDX(200)
      DIMENSION DU(200),DELSIG(200),DELSI2(200),ELSL2(200),DDELSIG(200),
     + D2YDX2(200)
      READ(88) VL3, AT, EID, NPTS, NCPTS
      IQUIT=0
      WRITE(6,42) NPTS,NCPTS
   42 FORMAT(1X,*NPTS=*,I5,3X,*NCPTS=*,I5)
      NC1=NCPTS+1    $NC2=NCPTS+2    $NC3=NCPTS+3    $NC4=NCPTS+4
      NM1=NPTS-1    $NM2=NPTS-2    $NM3=NPTS-3    $NM4=NPTS-4
      NM5=NPTS-5    $NM6=NPTS-6    $NP1 = NPTS+1
      READ(5,29) ICONTRL
   29 FORMAT(1I5)
      READ(61) (DYDX(I),I=1,NPTS)    $IF(ICONTRL.EQ.1)GO TO 150
      READ(20) SKIP $READ(20) (U(I),I=1,NM1) $GO TO 160
  150 READ(87) SKIP   $READ(87) (U(I),I=1,NM1)
      READ(87) SKIP   $READ(87) (U(I),I=1,NM1)
  160 CONTINUE
  C   WRITE(6,1) (U(I),I=1,NM1)
      READ(60)(X(I),Y(I),I=1,NPTS)    $WRITE(6,1)VL3, AT
    1 FORMAT(1H1,* VL3  = *, F10.6, 3X, * AT = *, F10.6)
  100 DO 100 I = 2,NM1
      U(I)=U(I-1)+(X(I)-X(I-1))*(U(I)-U(I-1))/(X(I+1)-X(I-1))
      U(1) = 0.0
      DUDX(1)=10.*100.*1000.
      DYDX(1) = (Y(2)-Y(1))/(X(2)-X(1))
      DO 101 I = 2,NM1
      U(I)=DU(I)
  101 U(NM4) = U(NM5)    +    (U(NM5)-U(NM6))
      U(NM3) = U(NM5)    +  2.*(U(NM5)-U(NM6))
      U(NM2) = U(NM5)    +  3.*(U(NM5)-U(NM6))
      U(NM1) = U(NM5)    +  4.*(U(NM5)-U(NM6))
      U(NPTS) = U(NM5)   +  5.*(U(NM5)-U(NM6))
      DELSIG(1)=0.0
      U(NP1) = U(SIGN)   $Y(NP1)=0.    $DYDX(NP1)=0.    $PI=3.14159
```

```
CALL INTR3(X,U,DUDX,NPTS,IER)
DUDX(NP1) = DUDX(NPTS)
CALL INTR3(X,DYDX,D2YDX2,NPTS,IER)
D2YDX2(1) = (DYDX(2)-DYDX(1))/(X(2)-X(1))
D2YDX2(2) = (DYDX(3)-DYDX(2))/(X(3)-X(2))
D2YDX2(NP1) = D2YDX2(NPTS)
      READ (5,49) ISB
49    FORMAT (I10)
      WRITE (6,99) ISB
99    FORMAT (//, 1X, *ISB  = *, I3)
      READ (5,70) ITRIP, XTRIP, IDRTH
70    FORMAT (I10, F10.6, I10)
      WRITE (6,71) ITRIP, XTRIP, IDRTH
71    FORMAT ( //, 1X, *ITRIP = *, I2, 3X, * XTRIP = *, F10.6, 3X,
     * *IDRTH = *,I4)
      READ (5,49) IFP
      WRITE (6,80) IFP
80    FORMAT (//, 1X, *IFP = *, I3)
      READ (5,49) ITLS
      WRITE (6,86) ITLS
86    FORMAT (//, 1X, * ITLS = *, I3)
      IF (IFP.NE.1) GO TO 83
      I = 1 (R CU
      II(I) = 1.
      DUDX(I) = 0.
      Y(I) = .5/FLD
      DYDX(I) = 0.
      CONTINUE
      VL3 = .25*PI/(FLD*FLD)
      AT = PI/FLD
      WRITE (6,82)
82    FORMAT (//, 1X, * THE FOLLOWING ARE FLAT-PLATE RESULTS CALCULATED
     * BY SETTING  U(I) = 1.0 AND  Y(I) = DIA./2 FOR ALL  I  *)
83    CONTINUE
      WRITE (6,4)
4     FORMAT(1H1,/4X*I*11X*X*14X*Y*14X*DUDX*11X*DYDX*11X*D2YDX2*/)
      WRITE (6,3)(I,X(I),Y(I),DUDX(I),DYDX(I),D2YDX2(I),I=1,NPTS)
```

```
   3   FORMAT(2X,I3.2X,6F15.5)
   8   READ(5,27)RL,J,L
  27   FORMAT (F10.3.2I5)
       IF(EOF(5))17,18
  18   WRITE(6,15)RL,J,L
  15   FORMAT(1H1,* RL = *,F12.5,*,J=*,I5,  *    L=*,I5//)
       WRITE (6,2)
   2   FORMAT ( /, 4X, *I*, 6X, *X*, 9X, *Y*, 9X, *U*, 9X, *PGP*,12X,
      + *RT *, 7X, *H*,14X,*RDS*,7X, *HFIA*, 6X, *DS*, / )
       CF = 0.
       RS = 1.
       DU = J.
       FLSL2(1) = 0.00000   $DX=.01   $XX=0.   $F0=0. $R0=0.
       A0 = 0.
       AI0 = 0.
       FE = 2.71828
       DO 21 I = 2,NPTS
       IF(I.EQ.NC1) DX = .002
       IF(I.EQ.NC2) DX = .003
       IF(I.EQ.NC3) DX = .005
       IF(I.EQ.NC4) DX = .010
       XX=XX+DX  $SECA=SQRT(1.+DYDX(I)**2)   $F=Y(I)*Y(I)*U(I)**5*SECA
       R=DX**(F0+F)/2.+H0  $H0=B   $FU=F   $RTH2RL=4.*B/(9.*U(I)**4*Y(I)*
      1Y(I))   $RTH=SQRT(RL*RTH2RL)  $OML2=RTH*Y(I)/(U(I)*RL)
       PGP = RTH2RL*DUDX(I)/(SECA*U(I)/(SFCA*U(I)*U(I)))
       H = 2.6028105-3.0919812*PGP-.010679l*PGP*PGP-493.8448682*PGP**3
      + +8597.6296884*PGP**4-37409.549516 *PGP**5
       RDS = H*RTH
       A = Y(I)*(U(I)*RTH*DYDX(I)*D2YDX2(I))/(SECA*SECA)
      + +RDS*DUDX(I))*DX/SECA
       AI = .5*(A0+A)*DX+AI0
       A0 = A
       AIC = AI
       BETA = -.0029568+2.56792*PGP+5.9997778*PGP*PGP+124.583A631*PGP**3
      + +1274.215228*PGP**4+1039.2030295*PGP**5
       DS = SFCA*DX
       FLSL2(I)= H*OML2
```

```
      YY = Y(I)
      IDDI = ID(I)
      WRITE(6,5) I, XX, YY, IDDI, PGP, RTH, H, RDS, BETA, DS
    5 FORMAT ( 2X, I3, 2X, 4F10.5, F15.5, F10.5, F15.5, 2F10.5)
      RS = RS+HL*SELA*DX
      CF = CF+2.*PI*Y(I)*.664*DX/(AI*SQRT(RS))
      IF(PGP .LT.-.09) GO TO 40
      PGF = 2.404+16.952*PGP+50.*PGP*PGP-817.71*PGP**3
      ALOGPGF=10.**PGF
      IF (ITRIP.NE.1) GO TO 74
      IF (XX.GE.XTRIP) GO TO 75
      IF(ABS(XX-XTRIP).LE.0.000000001)GO TO 75
      GO TO 74
   75 CONTINUE
      IF (IDRTH.NE.1) GO TO 79
      DRTH = .00005*AT/(2.*PI*Y(I)*SQRT(1.+DYDX(I)**2))
      RTH = RTH+DRTH
   79 CONTINUE
      GO TO 35
   74 CONTINUE
      IF (RTH.GE.ALOGPGF) GO TO 22
   21 CONTINUE
      IF(ICONTRL.EQ.1) GO TO 30    $DELDX(1)=0.0
      CALL DGT3(X,ELSL2,DFLDX,NPTS,IER)
      DELDX(NP1)=DELDX(NPTS)   $DO 19 IHID=2,NM1
      DELSIG(IHID)=(DYDX(IHID)*ELSL2(IHID)+U(IHID)*DELDX(IHID)*DELDX(IHID))*(SQRT(1.
     1+DYDX(IHID)**2))/(6.2832*Y(IHID))
   19 CONTINUE
   30 CONTINUE
      WRITE(6,24)   $GO TO 14
   24 FORMAT (/*PL IS SO SMALL THAT THE POINT OF NEUTRAL STABILITY IS
     1 NOT RFACHED*)
   22 RTHN=RTH
      FRTHN = RTH2RL*Y(I)*Y(I)/U(I)
      PGPN=PGP $UN=U(I)   $XN=XX   $YN=Y(I)   $IN=I
      CFN = CF
      WRITE(6,25) RTHN,PGPN,UN,XN,YN,H,IID, CFN
```

```
25 FORMAT(/,1X,*THN=*,F11.5,* PGPN=*,F11.5,* UN=*,F8.5,*
   1* YN=*,F8.5,* HN=*,E13.6,* IN=*,E14,* CFN = *,F11,H)
   F20 = Y(I)*Y(I)*SECA
   WRITE (6,25)
   DX=.001    DO 31 I=1,NPTS
   IF(I .GT. NC1) DX = .002
   IF(I.GT.NC2) DX = .003
   IF(I.GT.NC3) DX = .005
   IF(I.GT. NC4) DX = .010
   XX=XX+DX    $SECA=SQRT(1.+DYDX(I)**2)
   F=Y(I)*Y(I)*U(I)**5*SFCA    $R=DX*(F0+F)/2.+H0    $H0=R    $F0=F
   F0 = Y(I)*Y(I)*SECA
   H = D0+.5*(F00+F0)*DX
   F00 = F0
   D0 = 0
   RS = RS+RI*SECA*DX
   CF = CF+2.*PI*Y(I)*.664*DX/(AI*SQRT(RS))
   RTH2RL=4.*H/(4.*U(I)**4*Y(I))
   PGP=RTH2RL*DUDX(I)/(SECA*U(I)*U(I))
   RTH=SQRT(FL*RTH2RL) $OML2=RTH*Y(I)/(U(I)*RL)
   H = 2.902R1u5-3.0419412*PGP-.0106791*PGP*PGP-493.84486A2*PGP**3
   +  +8597.62968R9*PGP**4-37409.5+95169*PGP**5
   RDS = H*RTH
   A = Y(I)*(U(I)*RT*DYDX(I)*D2YDX2(I))/(SFCA*SFCA)
   +  *PDS*DUDX(I)*DX/SFCA
   AI = .5*(A0+A)*DX+AI0
   A0 = A
   AI0 = AI
   HETA = -.0024ub8+2.56792*PGP+c.99977TH*PGP*PGP+c.9947uH6*PGP**3
   +  +1274.21522RH*PGP**4+1035.7030295*PGP**5
   DS = SECA*DX
   FLSL2(I) = H*OML2
   TS1 = DYDX(I)/(I)*F1D)
   IF(PGP .LT.-.09) GO TO 40
   YY = Y(I)
   HOU = U(I)
   WRITE(6,5)  I, XX, YY, HHH, PGP, RTH, H, RDS, RETA, DS
```

109

```
      IF (IT*TP.NE.1) GO TO 76
      IF (XX.GE.XTRIP) GO TO 77
      IF(ABS(XX-XTRIP).LE.0.0000000001)GO TO 77
      GO TO 76
   77 CONTINUE
      IF (IDXTH.NE.1) GO TO 85
      DRTH = .00005*AT/(2.*PI*Y(I)*SQRT(1.+DYDX(I)**2))
      RTH = RTH+DRTH
   85 CONTINUE
      GO TO 35
   76 CONTINUE
      IF (I53.NE.1) GO TO 78
      HLAM = 4./45.-.2*(RTH2RL*T(I)*Y(I)/(U(I)-FRTHN)/D
      TP53 = 450.+490.*EF**(60.*HLAM)
      TF53 = 2.*FL1*(Y(I)*RTH-YG*RTHN)
      IF (TF53.GE.TP53) GO TO 35
      IF (I.LT.NPTS) GO TO 31
      GO TO 34
   74 CONTINUE
      GO TO 31
      IF (J.EQ.1) GO TO 37
      GO TO 38
   37 CONTINUE
      IF(TP.GE.-0.075)GO TO 45  BTF=671.8-2432.4*TP-930.4*TP*TP  $GOTO34
   45 CONTINUE
      IF ((TP.GE.0.165).AND.(L.EQ.1)) GO TO 46
      IF ((TP.GE.0.25).AND.(L.NE.1)) GO TO 47
      TF = 719.-1253.0*TP+5857.4*TP*TP*TP-7287.7*TP**3
      GO TO 34
   46 CONTINUE
      TF = 039.                 $GO TO 34
   47 CONTINUE
      TF = 551.+428.*TP         $GO TO 34
   38 CONTINUE
      IF(TP.LT.-0.02) GO TO 32
      TF=661.4-1910.3H*TP+1233.6*TP*TP+1036.5*TP**3      $GO TO 34
   32 CONTINUE
```

C

110

```
      TF = 671.*X-2.+32.4*TP-930.4*TP*TP
34    CONTINUE
      TFR=TF*RTHN
      IF (RTH.GT.TFR) GO TO 35
31    CONTINUE
      GO TO 34
35    RTHT=RTH    $IF=TF       $UT=U(I)       $XT=XX       $YT=Y(I)
      AIT = AI
      HT=1./(1.-(1./(0.617+0.3803*ALOG(RTHT))))
      T=T=RTHT/(RL*UT)   $IT=I   $OML2T=(RTHT*YT)/(UT*RL)      $TPT=TP
      CFT = CF
      CDFL = 4.*PI*(YT*UT*RTHT/SECA+AIT)/(AI*PL)
      WRITE (6,26) RTHT,UT, XT, YT, T, OML2T,HT, CFT, CDFL
26    FORMAT(/,1X,*RTHT=*,F11.5,* UT =*,F11.5,* XT =*,F8.5,* YT=*,F8.5,
     ** RT = *,E13.5,3X,* OML2T = *,F8.5,* HT = *, F10.5,* CFT = *,
     ** F11.5, /, 1X, *CDFL = *, F10.9, //)
      GOTO23
44    CONTINUE
      IF(ICONTRL.EQ.1) GO TO 33     $DELDX(1)=0.0
      CALL DGT3(X,ELSL2,DELDX,NPTS,IER)
      DELDX(NP1)=DELDX(NPTS)
      DO 20 ITRY=2,NM1
      DELSIG(ITRY)=(DUDX(ITRY)*ELSL2(ITRY)+U(ITRY)*DELDX(ITRY))*(SQRT(1.
     1+DYDX(ITRY)**2))/(6.2832*Y(ITRY))
20    CONTINUE
33    CONTINUE
      WRITE(6,36)             $GO TO 14
36    FORMAT(/* RL IS SO SMALL THAT THE TRANSITION POINT IS NOT REACHED*
     1 )
40    WRITE(6,6)  XX
6     FORMAT(1X,*LAMINAR SEPARATION OCCURS AT X=*,F7.5)
      IF ((PGP.LE.-.09).AND.(ITLS.EQ.1)) GO TO 35
      IQUIT=1+IQUIT
      IF(PGP.LF.-.09) GO TO 14
23    CONTINUE
12    FORMAT(1X,*FK=*,F15.8,10X,*SG=*,F15.8)    $IT=IT+1     $WRITE(6,13)
      H=HT          $TH=THT      $RTH=RTHT
```

111

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13 FORMAT(4X,*I*,6X,*OML2*,10X,*SIL2*,9X,*TH*,12X,*H*,
   112X,*SG*,12X,*LOG(RTH)*,6X,*CF*, /)
   $SFC1=SQRT(1.+DYDX(I+1)**2)
   K = 1
50 CONTINUE
   IF(H.GT.3.849) GO TO 96
   IF(I.GT.NC(1))DX=.002
   IF(I.GT.NC2))DX=.023
   IF(I.GT.NC3))DX=.065
   IF(I.GT.NC4))DX=.01
   F2=2.626*ALOG(RTH)-1.456-2.605*ALOG(((H-1.)**0.9392)/(H**1.9392))
   SG=11.          $FS=0.3462*(3.849-H)*SG/H+2.448*ALOG(SG)
51 IF(FS.GF.FR)GO TO 52
   SG=SG+100.  $FS=0.3462*(3.849-H)*(SG/H)+2.448*ALOG(SG)  $GO TO 51
52 CONTINUE
   SG=SG-10.   $FS=0.3462*(3.849-H)*SG/H+2.448*ALOG(SG)
   IF(FS.LT.FR) GO TO 53  $GO TO 52
53 CONTINUE
   SG=SG+1.    $FS=0.3462*(3.849-H)*SG/H+2.448*ALOG(SG)
   IF(FS.GF.FR) GO TO 54  $GO TO 53
54 CONTINUE
   SG=SG-.1    $FS=0.3462*(3.849-H)*SG/H+2.448*ALOG(SG)
   IF(FS.LT.FR)GOTO55  $GO TO 54
55 CONTINUE
   SG=SG+.01   $FS=0.3462*(3.849-H)*SG/H+2.448*ALOG(SG)
   IF(FS.GF.FR) GO TO 56  $GO TO 55
56 CONTINUE
   SG = SG-.001   $FS=0.3462*(3.849-H)*SG/H+2.448*ALOG(SG)
   IF (FS.LT.FR) GO TO 57  $GO TO 56
57 CONTINUE
   XX=XX+XX  $G=SG*(H-1.)/H
   HTL=H*H*(1.4857+(1.235/G)*(33.96/(G**2.75)))/(H-1.)-H
   DSH=2.4885/(H*(H-1.))*((1.346+(H-1.)*SG)+(2.606*H*(H-1.9392)))/
   G(3.849-H-SG+7.0/*H)
   DSR=7.27*H*((3.849-H)*SG+7.0/*H)
   DATH=(HTL*(H-/-)/(H*(H-1.))-(H**2/(H-1.))*((1.235/G)+(93.39/
   D(G**2.75)/))*((H-1.)/(H*H))-(DSH)+((1.1-H))*(.1639*(G-1.6)**2-1.81
   D(H=(.1639*(G+1.6))**2-1.81
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```
DHR=-H*H*(1.235/G+93.39/(G**2.75))*DSR/(H-1.)
EC=((H*(H+1.)/H)+1.)*(HTL+DHR)-DHTH*(H+(BE*(H+1.))))/(1.+(G*H/(
F2.666*((H-1.)**2)))
E=EC/(SG*SG)
HD=(.1028*H**6/(SG**3*(H-1.)**4))+
F(7.816*H**6/(SG**3*(H-1.))+
HD=.4457*(H**3)/(H-1.)+7.816*(H**6)/((H-1.)*SG)**3)/(H-1.)
DHPH=(.1028*H**(2.*H*H+.336*H-6.672))/((H-1.)**2)-(2.606*H**3)/(
HH-1.)*(.1021/SG+9.*H**3/((H-1.)**3*SG**3))*(DSH)+
V(.4746*H**2*(2.*H-3.))/(((H-1.)**2)*SG)+((15.636*H**5*(H-3.)
C)/((H-1.)**5)*(SG**3)))
DHPR=-((.4746*H**3/((H-1.)*SG)+(23.45*H**6/(((H-1.)**4)*(SG**3)))
F)*DSR
DHDH=((.4457*(H*H)*(2.*H-3.))/((H-1.)**2)-((23.45*H**6/(((H-1.)**
C4)*(SG**3)))*DSH)+(15.636*H**5*(H-3.)/(((H-1.)**5)*(SG**3)))
DHDR=-((23.45*H**6/(((H-1.)**4)*(SG**3))*DSR)
SECA = SQRT(1.+DYDX(I)**2)
IF(I.GT.IT1)GOTO16
OML2=Y(I)*TH+HP*TH*TH/SECA
PSIL2=Y(I)*HTL*TH+(.5*(HTL+ H)**2-HD)*TH*TH/SECA
16 FLSL2(I)=Y(I)*H*TH+HD*TH*TH/SECA
DY = (DYDX(I)+DYDX(I+1))**.5*DX  $DU = (DUDX(I)+DUDX(I+1))*.5*DX
IF (K.EQ.2) GO TO 62
IF (I.GE.NM5) GO TO 72
DOML2P = Y(I)*SECA*DX/(SG*SG)-(ELSL2(I)+2.*OML2 )*DU/U(I)
DPSIL2P = (Y(I)+(HTL+H)*TH)*SECA*E*DX-PSIL2 *DU/(U(I))
72 CONTINUE
OML2=OML2+DOML2P  $PSIL2=PSIL2+DPSIL2P          $GO TO 63
62 CONTINUE
IF (I.GE.NM5) GO TO 73
DOML2C=Y(I+1)*SEC1*DX/(SG*SG)-(ELSL2(I)+2.*OML2 )*DU/U(I+1)
DPSIL2C=(Y(I+1)+(HTL+H)*TH)*SEC1*E*DX-PSIL2 *DU/(U(I+1))
73 CONTINUE
OML2 = OML2 + .5*(DOML2C-DOML2P)
PSIL2 = PSIL2 + .5*(DPSIL2C-DPSIL2P)
63 CONTINUE
DCOS=1./(SEC1) -1./(SECA)  $IF (K.EQ.2) GO TO 66
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113

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      A1P    = Y(1   )+TH*(2.*HP+DHPR)/SECA      $H1P=TH*TH*DHPH/SECA
      C1P    = TH*(DY+TH*(HP*DCOS-DHPR*DU/(U(I  )*SECA)))
      A2P    = Y(I   )*TH*(HTL+DHP)+TH*((HTL+H)**2-.5*HD+(HTL+H)*DHR-DHDH)/
     *SECA    $B2P   = Y(I   )*TH*DHTH+TH*TH*(HTL+H)*(1.+DHTH)-DHDH)/SECA
      C2P    = TH*(HIL*DY+Y(I   )+DHP*DU/U(I   )+(.5*(HTL+H)**2-HD)*TH*DCOS
     *+TH*((HTL+H)*DHR-DHDR)*DU/(U(I   )*SECA))
      C3P    = DOML2P-C1P    $C4P=DPSIL2P-C2P
      TF (I.GE.NM5) GO TO 68
      DTHP   = (C3P*B2P-C4P*B1P)/(A1P*H2P-A2P*R1P)
      DHP    = (A1P*C4P-A2P*C3P)/(A1P*H2P-A2P*R1P)
   68 CONTINUE
      TH = TH+DTHP
      H = H+DHP    $GO TO67
   66 CONTINUE
      A1C    = Y(I+1)+TH*(2.*HP+DHPR)/SEC1      $H1C    = TH*TH*DHPH/SEC1
      C1C    = TH*(DY+TH*(HP*DCOS-DHPR*DU/(U(I+1)*SEC1)))
      A2C    = Y(I+1)*TH*((HTL+DHP)+(H*((HTL+H)**2-.5*HD+(HTL+H)*DHR-DHDR)/
     *SEC1    $B2C   = Y(I+1)*TH*DHTH+TH*TH*DHR*DU/U(I+1)+TH*(HTL+H)*(1.+DHTH)-DHDH)/SEC1
      C2C    = TH*(HIL*DY+Y(I+1)+DHP*DU/U(I+1)*SEC1)+(.5*(HTL+H)**2-HD)*TH*DCOS
     *+TH*((HTL+H)*DHR-DHDR)*DU/(U(I+1)*SEC1))
      C3C    = DOML2C-C1C    $C4C=DPSIL2C-C2C
      IF (I.GE.NM5) GO TO 50
      DTHC   = (C3C*H2C-C4C*R1C)/(A1C*B2C-A2C*R1C)
      DHC    = (A1C*C4C-A2C*C3C)/(A1C*H2C-A2C*B1C)
   50 CONTINUE
      TH = TH+.5*(DTHC-DTHP)
      H = H+.5*(DHC-DHP)
   57 CONTINUE
      RTH = TH*U(I)*RL    $ALRTH=ALOG(RTH)     $IF(K.EQ.1)GOTO64    $GOTO65
   64 CONTINUE     $K=2        $GO TO 61
   65 CONTINUE
      CF = CF+2.*PI*Y(I)*2.*DX/(SG*SG*AT)
      WRITE(6,11) I,OML2,PSIL2,ELSL2(I),TH,H,SG,ALRTH, CF
   11 FORMAT( 2X,I3,1X,8F14.8)
   60 CONTINUE
      IF(ICONTRL.EQ.1) GO TO 39    $DELDX(1)=0.0
      CALL DGT3(X,ELSL2,DFLDX,NPTS,IER)
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      DELDX(NP1)=DELDX(NPTS)
      DO 28 ICAN=2,NM5
      DELSIG(ICAN) =    (DUDX(ICAN)*ELSL2(ICAN)+U(ICAN)*DELDX(ICAN))*
     *(SQRT(1.+DYDX(ICAN)**2))/(6.2832*Y(ICAN))
   28 CONTINUE
      DELSIG(NM4) = DELSIG(NM5)+     (DELSIG(NM5)-DELSIG(NM6))
      DELSIG(NM3) = DELSIG(NM5)+2.* (DELSIG(NM5)-DELSIG(NM6))
      DELSIG(NM2) = DELSIG(NM5)+3.* (DELSIG(NM5)-DELSIG(NM6))
      DELSIG(NM1) = DELSIG(NM5)+4.* (DELSIG(NM5)-DELSIG(NM6))
      DELSIG(NPTS) = DELSIG(NM5)+5.* (DELSIG(NM5)-DELSIG(NM6))
      DELSIG(NP1) = DELSIG(NPTS)
   39 CONTINUE
      I = NPTS    $HE=H     $THE=TH    $OML2E=OML2    $PSIL2E=PSIL2
      ELSL2E=ELSL2(I)    $SHE=ELSL2E/OML2E    $UE=U(I)
      WRITE(6,9)HE,THE,OML2E,PSIL2E,ELSL2E,SHE,UE
    9 FORMAT(/1X,* HE = *,F10.5,* THE = *,F10.5,* OML2E = *,F10.5,* PSIL
     N2E = *,F10.5,* ELSL2E = *,F10.5,* SHE= *,F10.5,* UE=*,F9.5/)
      OML2D=OML2E*(UE**(.875*SHE+2.125))
      CD=4.*PI*OML2D/(VL3**.66667)    $WRITE(6,10)    $WRITE(6,7) CD
   10 FORMAT(1X,*CD IS THE DRAG COEFFICIENT BASED ON THE 2/3 POWER OF TH
     *E VOLUME*)
    7 FORMAT(1X,*    CD = *,F12.9)
      CS=CD*(VL3**.66667)/AT
      WRITE(6,58)
   58 FORMAT(1X,*CS IS THE DRAG COEFFICIENT BASED ON THE WETTED AREA*)
      WRITE(6,59) CS     CS=*,F12.9)
   59 FORMAT(1X,*
      IF(ICONTRL.EQ.1) GO TO 17
      DO 43 I=2,NM1
      DDELSIG(I)=DELSIG(I)+(X(I)-X(I-1))*(DELSIG(I)-DELSIG(I-1)) /
     1(X(I+1)-X(I))
   43 CONTINUE
      DDELSIG(NPTS)=0.5*(DELSIG(NM1)+DELSIG(NPTS))
      DO 44 I=1,NM1
      DELSIG(I)=DDELSIG(I+1)
   44 CONTINUE
      DELSIG(NPTS)=DELSIG(NM1)
```

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      WRITE(94)(DELSIG(I),I=1,NM1)
      ENDFILE 94
      GO TO 14
96    WRITE(6,97) H
97    FORMAT (1X,* H = *, F20.9, *  , WHICH IS TOO LARGE*)
48    CALL 4MORINE
14    GOTO8
17    CONTINUE
      IF([UUIT.GT.0) GO TO 48
      END


      SUBROUTINE DGF3(X,Y,Z,NDIM,IER)
      DIMENSION X(200),Y(200),Z(200)
      IER=-1  $IF(NDIM-3)8,1,1
1     A=X(1)  $H=Y(1)   $I=2  $DY2=X(2)-A
      IF(DY2)2,9,2
2     DY2=(Y(2)-H)/DY2
      DO 6 I=3,NDIM  $A=X(I)-A   $IF(A)3,9,3
3     A=(Y(I)-H)/A
      H=X(I)-X(I-1)   $IF(H)4,9,4
4     DY1=DY2
      DY2=(Y(I)-Y(I-1))/H  $DY3=A  $A=X(I-1)  $R=Y(I-1)  $IF(I-3)5,5,6
5     Z(I)=DY1+DY3-DY2
6     Z(I-1)=DY1+DY2-DY3
      IER=0   $I=NDIM
7     Z(I)=DY2+DY3-DY1
      RETURN
8     IER=I
9     I=I-1          $IF(I-2)8,8,7
      END
```

116

NPTS= 123   NCPTS= 101

VL3   =   .038862   AT =   .059399

I53   =   0

ITRIP =   0   XTRIP =   .100000   IDKTH =   0

IFP =   0

ITLS =   1

I	X	Y	U	DUDX	DYDX	D2YDX2
1	0.00000	0.00000	0.00000	1000000.00000	8.73687	-4366.56806
2	.00100	.00874	.20759	163.42493	4.37030	-1278.10454
3	.00200	.01236	.32685	91.10223	3.09220	-922.00393
4	.00300	.01514	.38980	56.65309	2.52630	-451.54150
5	.00400	.01748	.44016	45.95135	2.18912	-283.59162
6	.00500	.01955	.48170	38.41603	1.95911	-199.86093
7	.00600	.02142	.51699	32.93499	1.78939	-150.79083
8	.00700	.02314	.54757	28.74247	1.65753	-119.06388
9	.00800	.02475	.57447	25.42029	1.55127	-97.13343
10	.00900	.02625	.59841	22.71883	1.46326	-81.21942
11	.01000	.02768	.61991	20.47825	1.38883	-69.23512
12	.01100	.02903	.63937	18.59057	1.32479	-59.94219
13	.01200	.03033	.65709	16.97971	1.26894	-52.56334
14	.01300	.03157	.67333	15.59035	1.21967	-46.58832
15	.01400	.03277	.68827	14.38109	1.17577	-41.66955
16	.01500	.03393	.70209	13.32020	1.13633	-37.56290
17	.01600	.03504	.71491	12.38311	1.10064	-34.09235
18	.01700	.03613	.72686	11.55034	1.06814	-31.12809

19	.C1800	.371H	.73H01	10.HO625	1.0383H	-28.57253
20	.C1900	.3H21	.74H47	10.13H16	1.01100	-26.35098
21	.02000	.3920	.75H29	9.53564	.98568	-24.40547
22	.02100	.4018	.7675+	H.9400H	.96219	-22.69032
23	.02200	.4113	.77627	H.49425	.94030	-21.16915
24	.02300	.4266	.78453	H.04210	.91985	-19.81266
25	.02400	.4297	.79235	7.62H49	.90068	-18.59697
26	.02500	.4386	.79979	7.24901	.88266	-17.50251
27	.02600	.4474	.806H5	6.H9991	.86567	-16.51305
28	.02700	.4559	.H135H	6.57795	.84963	-15.61505
29	.02800	.4643	.H2001	6.2H030	.H3444	-14.79714
30	.02900	.4726	.H2615	6.03452	.82003	-14.04971
31	.03000	.4H0H	.H3202	5.74H47	.80634	-13.36458
32	.03100	.4HH7	.H3764	5.51025	.79331	-12.73473
33	.03200	.4966	.H430H	5.2HH21	.78087	-12.15416
34	.03300	.5044	.H4H2H	5.0HOH9	.76900	-11.61765
35	.03400	.5120	.H5320	4.H6H99	.75764	-11.12069
36	.03500	.5195	.H5799	4.70532	.74676	-10.65933
37	.03600	.5269	.H6261	4.53HH7	.73632	-10.23012
3H	.03700	.5342	.H6706	4.37473	.72630	-9.83004
39	.03H00	.5415	.H7136	4.22404	.71666	-9.45640
40	.03900	.54H0	.H7551	4.0H207	.70738	-9.10684
41	.04000	.5556	.H7952	3.94H13	.69845	-8.77925
42	.04100	.5626	.HH341	3.H2163	.68982	-8.47177
43	.04200	.5694	.H8717	3.70200	.68150	-8.18272
44	.04300	.5762	.H9081	3.5HH75	.67346	-7.91060
45	.04400	.5H29	.H9434	3.4H142	.66568	-7.65407
46	.04500	.5H95	.H9777	3.37958	.65815	-7.41192
47	.04600	.5960	.90110	3.2H2H7	.65086	-7.18305
48	.04700	.6025	.90434	3.19094	.64378	-6.96647
49	.04H00	.60H9	.90749	3.10347	.63692	-6.76129
50	.04900	.6153	.9105H	3.02017	.63026	-6.56670
51	.05000	.6215	.91353	2.94077	.62379	-6.38195
52	.05100	.6277	.91643	2.H6501	.61750	-6.20636
53	.05200	.6339	.91926	2.79268	.61138	-6.03932
54	.05300	.6400	.92201	2.72357	.60542	-5.88027
55	.05400	.6460	.9247J	2.6574H	.59962	-5.72869

118

56	.05500	.06520	.92773	2.59424	.59396	-5.58409
57	.05600	.06579	.92989	2.53357	.58845	-5.44604
58	.05700	.06637	.93240	2.47562	.58307	-5.31415
59	.05800	.06695	.93484	2.41995	.57782	-5.18803
60	.05900	.06753	.93724	2.36653	.57269	-5.06735
61	.06000	.06810	.93958	2.31523	.56769	-4.95178
62	.06100	.06866	.94187	2.26593	.56279	-4.84103
63	.06200	.06922	.94411	2.21853	.55800	-4.73483
64	.06300	.06978	.94630	2.17294	.55332	-4.63293
65	.06400	.07033	.94845	2.12904	.54874	-4.53509
66	.06500	.07088	.95056	2.08677	.54425	-4.44108
67	.06600	.07142	.95263	2.04602	.53986	-4.35071
68	.06700	.07196	.95465	2.00674	.53555	-4.26378
69	.06800	.07249	.95664	1.96885	.53133	-4.18012
70	.06900	.07302	.95859	1.93227	.52719	-4.09956
71	.07000	.07354	.96051	1.89693	.52313	-4.02194
72	.07100	.07407	.96238	1.86279	.51915	-3.94713
73	.07200	.07458	.96423	1.82979	.51523	-3.87497
74	.07300	.07510	.96604	1.79788	.51140	-3.80534
75	.07400	.07561	.96783	1.76700	.50762	-3.73813
76	.07500	.07611	.96958	1.73710	.50392	-3.67321
77	.07600	.07661	.97130	1.70814	.50028	-3.61049
78	.07700	.07711	.97299	1.68009	.49670	-3.54986
79	.07800	.07761	.97466	1.65290	.49318	-3.49123
80	.07900	.07810	.97630	1.62654	.48972	-3.43450
81	.08000	.07859	.97791	1.60096	.48631	-3.37960
82	.08100	.07907	.97950	1.57612	.48296	-3.32644
83	.08200	.07955	.98107	1.55202	.47966	-3.27495
84	.08300	.08003	.98261	1.52861	.47641	-3.22506
85	.08400	.08051	.98412	1.50586	.47321	-3.17670
86	.08500	.08098	.98562	1.48377	.47005	-3.12981
87	.08600	.08145	.98709	1.46228	.46695	-3.08433
88	.08700	.08191	.98854	1.44137	.46388	-3.04019
89	.08800	.08237	.98997	1.42104	.46087	-2.99735
90	.08900	.08243	.99138	1.40127	.45789	-2.95576
91	.09000	.08329	.99278	1.38205	.45495	-2.91536
92	.09100	.08374	.99415	1.36338	.45206	-2.87611

93	.09200	.08419	.99550	1.34524	.44920	-2.83796
94	.09300	.08464	.99684	1.32763	.44638	-2.80088
95	.09400	.08509	.99816	1.31064	.44360	-2.76482
96	.09500	.08553	.99946	1.29439	.44085	-2.72974
97	.09603	.08597	1.00075	1.27917	.43814	-2.69561
98	.09700	.08640	1.00202	1.26597	.43546	-2.66240
99	.09400	.08684	1.00328	1.25710	.43242	-2.63006
100	.09900	.08727	1.00453	1.14040	.43020	-2.59857
101	.10000	.08770	1.00564	1.04963	.42762	-2.56803
102	.10200	.08855	1.00776	1.03480	.42254	-2.50952
103	.10500	.08901	1.01086	1.01542	.41514	-2.42740
104	.11000	.09185	1.01561	.95593	.40333	-2.30491
105	.12000	.09577	1.02573	.97735	.38142	-2.09676
106	.13000	.09949	1.03519	.93016	.36140	-1.92605
107	.14000	.10301	1.04390	.83543	.34290	-1.78699
108	.15000	.10635	1.05187	.76464	.32566	-1.67209
109	.16000	.10952	1.05917	.70436	.30946	-1.57595
110	.17000	.11254	1.06596	.65172	.29414	-1.49463
111	.18000	.11541	1.07223	.60448	.27957	-1.42516
112	.19000	.11813	1.07806	.56263	.26564	-1.36529
113	.20000	.12072	1.08345	.52407	.25226	-1.31326
114	.21000	.12318	1.08854	.48855	.23937	-1.26771
115	.22000	.12551	1.09325	.45556	.22691	-1.22755
116	.23000	.12772	1.09765	.42470	.21482	-1.19190
117	.24030	.12981	1.10175	.34568	.20307	-1.16007
118	.25000	.13178	1.10556	.36824	.19162	-1.13148
119	.26000	.13364	1.10911	.34221	.18044	-1.10563
120	.27000	.13539	1.11241	.31744	.16951	-1.08214
121	.28000	.13703	1.11546	.29342	.15880	-1.06067
122	.29000	.13857	1.11824	.27128	.14829	-1.04094
123	.30000	.14000	1.12089	.24975	.13748	-1.02270
124	.31000	.14133	1.12328	.22923	.12784	-1.00575
125	.32000	.14256	1.12547	.20971	.11786	-.98990
126	.33000	.14369	1.12747	.19123	.10804	-.97501
127	.34000	.14472	1.12929	.17384	.09836	-.96093
128	.35000	.14565	1.13095	.15766	.08882	-.94755
129	.36000	.14650	1.13245	.14243	.07941	-.93475

130	.37000	.14724	1.13341	.12967	.07013	-.92243
131	.38000	.14770	1.13504	.11821	.06096	-.91051
132	.39000	.14846	1.13617	.10920	.05192	-.89891
133	.40000	.14894	1.13724	.10325	.04298	-.88754
134	.41000	.14932	1.13823	.10140	.03417	-.87634
135	.42000	.14962	1.13925	.10593	.02546	-.86524
136	.43000	.14983	1.14035	.12117	.01686	-.85416
137	.44000	.14996	1.14168	.15492	.00837	-.84306
138	.45000	.15000	1.14345	.20404	-.00000	-.86484
139	.46000	.14996	1.14576	.24136	-.00892	-.94717
140	.47000	.14982	1.14822	.24294	-.01894	-1.04963
141	.48000	.14957	1.15052	.21200	-.02991	-1.13777
142	.49000	.14922	1.15252	.16139	-.04170	-1.21284
143	.50000	.14874	1.15384	.09886	-.05417	-1.27600
144	.51000	.14813	1.15450	.02867	-.06722	-1.32831
145	.52000	.14739	1.15442	-.04634	-.08074	-1.37076
146	.53000	.14652	1.15357	-.12410	-.09463	-1.40423
147	.54000	.14556	1.15194	-.20301	-.10882	-1.42951
148	.55000	.14434	1.14951	-.28183	-.12322	-1.44730
149	.56000	.14303	1.14630	-.35957	-.13777	-1.45826
150	.57000	.14155	1.14232	-.43540	-.15239	-1.46295
151	.58000	.13999	1.13759	-.50870	-.16703	-1.46185
152	.59000	.13844	1.13214	-.57894	-.18163	-1.45543
153	.60000	.13635	1.12601	-.64573	-.19614	-1.44406
154	.61000	.13412	1.11923	-.70877	-.21051	-1.42807
155	.62000	.13214	1.11184	-.76783	-.22470	-1.40778
156	.63000	.12983	1.10387	-.82278	-.23866	-1.38342
157	.64000	.12737	1.09538	-.87351	-.25237	-1.35522
158	.65000	.12478	1.08640	-.92000	-.26577	-1.32335
159	.66000	.12206	1.07698	-.96226	-.27883	-1.28796
160	.67000	.11941	1.06716	-1.00032	-.29153	-1.24917
161	.68000	.11623	1.05697	-1.03427	-.30382	-1.20707
162	.69000	.11313	1.04647	-1.06420	-.31567	-1.16174
163	.70000	.10922	1.03569	-1.09022	-.32705	-1.11319
164	.71000	.10599	1.02467	-1.11245	-.33793	-1.06145
165	.72000	.10316	1.01344	-1.13102	-.34828	-1.00649
166	.73000	.09965	1.00205	-1.14665	-.35806	-.94829

167	.74000	.09690	.99052	-1.15768	-.36725	-.88676
168	.75000	.09228	.97889	-1.16600	-.37580	-.82182
169	.76000	.08849	.96721	-1.17113	-.38368	-.75332
170	.77000	.08401	.95547	-1.17314	-.39046	-.68111
171	.78000	.08007	.94374	-1.17210	-.39730	-.60497
172	.79000	.07661	.93203	-1.16804	-.40296	-.52466
173	.80000	.07262	.92038	-1.16095	-.40780	-.43987
174	.81000	.06852	.90881	-1.15079	-.41176	-.35023
175	.82000	.06438	.89736	-1.13746	-.41480	-.25531
176	.83000	.06022	.88606	-1.12081	-.41687	-.15456
177	.84000	.05605	.87494	-1.10058	-.41789	-.04734
178	.85000	.05187	.86405	-1.07643	-.41781	.06714
179	.86000	.04770	.85342	-1.04787	-.41655	.18986
180	.87000	.04354	.84309	-1.01425	-.41402	.32202
181	.88000	.03942	.83313	-.97465	-.41011	.46514
182	.89000	.03535	.82363	-.92782	-.40471	.62117
183	.90000	.03133	.81457	-.87204	-.39769	.79264
184	.91000	.02749	.80616	-.80486	-.38886	.98291
185	.92000	.02356	.79848	-.72280	-.37803	1.19657
186	.93000	.01985	.79170	-.62065	-.36493	1.44008
187	.94000	.01627	.78606	-.49049	-.34923	1.72289
188	.95000	.01287	.78189	-.41719	-.33047	2.05949
189	.96000	.00967	.77772	-.41719	-.30804	2.47362
190	.97000	.00673	.77355	-.41719	-.28100	3.00746
191	.98000	.00407	.76938	-.41719	-.24789	3.74575
192	.99000	.00180	.76520	-.41719	-.20608	4.89436
193	1.00000	.00000	.76103	-.41719	-.15000	6.32235

122

RL = .50000E+07 J= 1 I= 1

I	X	Y	U	PGP	KTH	H	RDS	BETA	DS
2	.00100	.00874	.20769	.17494	32.15752	1.34060	43.11024	2.66065	.00448
3	.00200	.01236	.32685	.07077	36.72129	2.35816	86.59467	.28677	.00325
4	.00300	.01514	.38980	.05516	44.83070	2.40983	108.03426	.19019	.00272
5	.00400	.01748	.44016	.05216	51.44339	2.42061	124.52452	.17483	.00241
6	.00500	.01955	.48170	.04981	57.52198	2.42920	139.73214	.16340	.00220
7	.00600	.02142	.51699	.04802	63.19758	2.43580	153.93649	.15502	.00205
8	.00700	.02314	.54757	.04654	68.54716	2.44129	167.34336	.14829	.00194
9	.00800	.02475	.57447	.04525	73.62616	2.44608	180.09562	.14259	.00185
10	.00900	.02625	.59841	.04409	78.47619	2.45039	192.29737	.13760	.00177
11	.01000	.02768	.61991	.04304	83.12924	2.45433	204.02699	.13312	.00171
12	.01100	.02903	.63937	.04206	87.61052	2.45798	215.34502	.12906	.00166
13	.01200	.03033	.65709	.04115	91.93997	2.46138	226.29935	.12533	.00162
14	.01300	.03157	.67333	.04030	96.13393	2.46457	236.92855	.12190	.00158
15	.01400	.03277	.68827	.03950	100.20579	2.46756	247.26426	.11871	.00154
16	.01500	.03393	.70209	.03874	104.16683	2.47039	257.33299	.11574	.00151
17	.01600	.03504	.71491	.03803	108.02656	2.47307	267.15700	.11296	.00149
18	.01700	.03613	.72686	.03735	111.79311	2.47560	276.75527	.11036	.00146
19	.01800	.03718	.73801	.03670	115.47353	2.47801	286.14423	.10791	.00144
20	.01900	.03821	.74847	.03609	119.07392	2.48029	295.33816	.10561	.00142
21	.02000	.03920	.75829	.03550	122.59967	2.48247	304.34965	.10344	.00140
22	.02100	.04018	.76754	.03495	126.05554	2.48454	313.18983	.10138	.00139
23	.02200	.04113	.77627	.03441	129.44578	2.48651	321.86862	.09944	.00137
24	.02300	.04206	.78453	.03391	132.77418	2.48840	330.39493	.09760	.00136
25	.02400	.04297	.79235	.03342	136.04416	2.49020	338.77680	.09585	.00135
26	.02500	.04386	.79979	.03295	139.25882	2.49192	347.02150	.09418	.00133
27	.02600	.04474	.80685	.03251	142.42097	2.49356	355.13568	.09260	.00132
28	.02700	.04559	.81358	.03208	145.53318	2.49514	363.12542	.09110	.00131
29	.02800	.04643	.82001	.03167	148.59781	2.49665	370.99628	.08966	.00130
30	.02900	.04726	.82615	.03128	151.61702	2.49809	378.75343	.08829	.00129
31	.03000	.04808	.83202	.03090	154.59281	2.49948	386.40160	.08698	.00128
32	.03100	.04887	.83764	.03053	157.52702	2.50081	393.94521	.08573	.00128
33	.03200	.04966	.84314	.03018	160.42137	2.50209	401.38839	.08453	.00127

34	.03300	.05044	.74822	163.27745	2.50332	408.73494	.08339	.00126
35	.03400	.05120	.75370	165.09676	2.50449	415.98842	.08229	.00125
36	.03500	.05195	.75799	168.98068	2.50563	423.15229	.08124	.00125
37	.03600	.05269	.76261	171.63652	2.50672	430.22966	.08023	.00124
38	.03700	.05342	.76746	174.34749	2.50777	437.23345	.07926	.00124
39	.03800	.05415	.77136	177.03276	2.50878	444.13648	.07833	.00123
40	.03900	.05486	.77551	179.68740	2.50976	450.97140	.07743	.00122
41	.04000	.05556	.77952	182.31243	2.51069	457.73069	.07657	.00122
42	.04100	.05626	.78341	184.90881	2.51160	464.41674	.07575	.00121
43	.04200	.05694	.78717	187.47748	2.51247	471.03182	.07495	.00121
44	.04300	.05762	.79091	190.01928	2.51331	477.57800	.07418	.00121
45	.04400	.05829	.79434	192.53504	2.51413	484.05737	.07345	.00120
46	.04500	.05895	.79777	195.02555	2.51491	490.47188	.07273	.00120
47	.04600	.05960	.80110	197.49155	2.51567	496.82334	.07205	.00119
48	.04700	.06025	.80434	199.93374	2.51640	503.11352	.07139	.00119
49	.04800	.06090	.80749	202.35281	2.51711	509.34409	.07075	.00119
50	.04900	.06153	.81055	204.74940	2.51779	515.51665	.07013	.00118
51	.05000	.06215	.81353	207.12411	2.51846	521.63277	.06953	.00118
52	.05100	.06277	.81643	209.47755	2.51910	527.69397	.06896	.00118
53	.05200	.06339	.81926	211.81629	2.51972	533.70163	.06840	.00117
54	.05300	.06400	.82201	214.12285	2.52032	539.65708	.06786	.00117
55	.05400	.06460	.82470	216.41576	2.52090	545.56165	.06734	.00117
56	.05500	.06520	.82733	218.68952	2.52146	551.41661	.06684	.00116
57	.05600	.06579	.82989	220.94460	2.52200	557.22317	.06635	.00116
58	.05700	.06637	.83240	223.18147	2.52253	562.98249	.06588	.00116
59	.05800	.06695	.83484	225.40057	2.52304	568.69569	.06542	.00115
60	.05900	.06753	.83724	227.60231	2.52354	574.36383	.06498	.00115
61	.06000	.06810	.83958	229.78712	2.52402	579.98798	.06455	.00115
62	.06100	.06866	.84187	231.95539	2.52449	585.56922	.06413	.00115
63	.06200	.06922	.84411	234.10750	2.52494	591.10848	.06373	.00115
64	.06300	.06978	.84630	236.24382	2.52539	596.60664	.06334	.00114
65	.06400	.07033	.84845	238.36471	2.52581	602.06466	.06296	.00114
66	.06500	.07088	.85056	240.47050	2.52623	607.48342	.06259	.00114
67	.06600	.07162	.85263	242.56153	2.52663	612.86378	.06223	.00114
68	.06700	.07196	.85465	244.63812	2.52702	618.20656	.06189	.00113
69	.06800	.07249	.85664	246.70059	2.52741	623.51248	.06155	.00113
70	.06900	.07302	.85849	248.74922	2.52778	628.78239	.06122	.00113

71	.07000	.07354	.46751	.05292	250.78431	2.52914	634.01722	.06090	.00113
72	.07100	.07407	.46218	.05282	252.40617	2.52849	639.21756	.06059	.00113
73	.07200	.07458	.46423	.05272	254.41504	2.52883	644.38397	.06029	.00112
74	.07300	.07510	.46654	.05262	255.81120	2.52916	649.51726	.05999	.00112
75	.07400	.07561	.46783	.05253	257.79490	2.52449	654.61822	.05971	.00112
76	.07500	.07611	.46958	.05244	260.76640	2.52980	659.68743	.05943	.00112
77	.07600	.07661	.47135	.05235	262.72594	2.53011	664.72543	.05916	.00112
78	.07700	.07711	.47299	.05227	264.67376	2.53041	669.73291	.05890	.00112
79	.07800	.07761	.47406	.05218	266.61309	2.53070	674.71042	.05864	.00111
80	.07900	.07810	.47630	.05210	268.53514	2.53099	679.65852	.05839	.00111
81	.08000	.07859	.47791	.05202	270.44913	2.53126	684.57791	.05814	.00111
82	.08100	.07907	.47925	.05195	272.35229	2.53153	689.46919	.05790	.00111
83	.08200	.07955	.48157	.05187	274.24482	2.53180	694.33270	.05767	.00111
84	.08300	.08003	.48261	.05180	276.12690	2.53206	699.16896	.05745	.00111
85	.08400	.08051	.48412	.05172	277.99874	2.53231	703.97862	.05722	.00111
86	.08500	.08099	.48562	.05165	279.86053	2.53255	708.76192	.05701	.00110
87	.08600	.08145	.48769	.05158	281.71244	2.53279	713.51949	.05680	.00110
88	.08700	.08191	.48854	.05152	283.55466	2.53303	718.25205	.05659	.00110
89	.08800	.08237	.48997	.05145	285.38737	2.53326	722.95965	.05639	.00110
90	.08900	.08283	.49138	.05139	287.21072	2.53348	727.64256	.05620	.00110
91	.09000	.08329	.49278	.05132	287.02447	2.53370	732.30114	.05601	.00110
92	.09100	.08374	.49415	.05126	290.82997	2.53390	736.93538	.05582	.00110
93	.09200	.08419	.49554	.05121	292.62613	2.53411	741.54570	.05565	.00110
94	.09300	.08464	.49644	.05115	294.41361	2.53430	746.13192	.05548	.00110
95	.09400	.08509	.49816	.05110	296.19218	2.53448	750.69254	.05532	.00110
96	.09500	.08553	.49946	.05105	297.46215	2.53464	755.22538	.05518	.00109
97	.09600	.08597	1.00075	.05102	297.72337	2.53475	759.72466	.05508	.00109
98	.09700	.08640	1.00252	.05101	301.47546	2.53477	764.17178	.05506	.00109
99	.09800	.08684	1.03028	.05108	303.21718	2.53456	768.52158	.05525	.00109
100	.09900	.08727	1.04053	.04998	304.94541	2.53432	774.05011	.05196	.00109
101	.10000	.08770	1.05564	.04849	305.74554	2.54345	780.19307	.04750	.00109
102	.10200	.08855	1.07770	.04816	310.38612	2.54457	789.79971	.04653	.00109
103	.10500	.08981	1.11046	.04829	315.66504	2.54412	803.08901	.04693	.00217
104	.11000	.09185	1.15611	.04610	324.46136	2.54477	825.68111	.04636	.00325
105	.12000	.09577	1.25530	.05010	340.86297	2.53763	864.98495	.05256	.00539
106	.13000	.09949	1.3515	.05049	356.00534	2.53588	902.78693	.05409	.01070
107	.14000	.10291	1.4340	.05007	370.95672	2.53838	941.61537	.05191	.01057

I	X	Y	U	PGP	RTH	H	RDS	BETA	DS
108	.15000	.1636	1.7107	.01464	382.58316	2.53985	979.32478	.05063	.01052
109	.16000	.1652	1.5919	.01918	397.91446	2.54107	1016.21995	.04957	.01047
110	.17000	.1256	1.6546	.01896	413.98737	2.54217	1052.42804	.04861	.01042
111	.18000	.1541	1.7273	.01855	427.82294	2.54324	1088.05587	.04769	.01038
112	.19000	.1813	1.7806	.01824	441.45738	2.54430	1123.20022	.04677	.01035
113	.20000	.1072	1.8348	.01792	454.92117	2.54539	1157.95001	.04583	.01031
114	.21000	.1314	1.8854	.01754	467.24281	2.54651	1192.38728	.04485	.01028
115	.22000	.1551	1.8325	.01723	481.44487	2.54776	1226.58793	.04383	.01025
116	.23000	.1272	1.9765	.01686	494.56416	2.54896	1260.62254	.04274	.01023
117	.24000	.1291	1.10175	.01644	507.61188	2.55029	1294.55693	.04159	.01020
118	.25000	.1317	1.13554	.01604	520.61380	2.55170	1328.45258	.04038	.01018
119	.0009?	.1344	1.16711	.01554	533.59038	2.55321	1362.36698	.03908	.01016

RTHN= 533.59039 PGPN= .01559 UN=1.10011 XN=.26000

YN= .13364 HN= .346273E-02 TN= 119 CFN = .00017217

I	X	Y	U	PGP	RTH	H	RDS	BETA	DS
120	.27000	.13539	1.11241	.01511	548.56096	2.55480	1396.35385	.03771	.01014
121	.28000	.13703	1.11546	.01460	557.54376	2.55644	1430.46317	.03627	.01013
122	.29000	.13857	1.11828	.01497	572.55603	2.55425	1464.74112	.03476	.01011
123	.30000	.14000	1.12049	.01351	543.51405	2.56010	1499.22969	.03317	.01009
124	.31000	.14133	1.12368	.01202	594.73312	2.56202	1535.96615	.03153	.01008
125	.32000	.14256	1.12567	.01231	611.72750	2.56400	1568.98211	.02984	.01007
126	.33000	.14369	1.12747	.01149	622.21035	2.56602	1604.30208	.02811	.01006
127	.34000	.14472	1.12922	.01106	634.54344	2.56905	1639.94139	.02638	.01005
128	.35000	.14565	1.13045	.01044	652.04714	2.57066	1675.90308	.02467	.01004
129	.36000	.14650	1.13245	.00984	662.69949	2.57199	1712.17327	.02302	.01003
130	.37000	.14724	1.13341	.00928	677.43604	2.57377	1748.71403	.02151	.01002
131	.38000	.14790	1.13564	.00880	693.29865	2.57530	1785.45215	.02021	.01002
132	.39000	.14846	1.13617	.00845	707.28406	2.57642	1822.26071	.01926	.01001
133	.40000	.14894	1.13722	.00830	721.38144	2.57690	1858.92642	.01885	.01001
134	.41000	.14932	1.13823	.00847	735.56836	2.57636	1895.08632	.01931	.01001
135	.42000	.14962	1.13925	.00917	749.80313	2.57412	1930.08297	.02121	.01000
136	.43000	.14983	1.14035	.01087	764.00816	2.56867	1962.48716	.02585	.01000
137	.44000	.14996	1.14148	.01439	778.01734	2.55719	1989.54015	.03566	.01000
138	.45000	.15000	1.14345	.01955	791.53544	2.53980	2010.34229	.05067	.01000
139	.46000	.14996	1.14576	.02340	804.49127	2.52504	2031.37118	.06365	.01000

140	.47000	.14982	1.14828	.02462	817.39001	2.52213	.06624	.01000
141	.48000	.14957	1.15062	.02210	830.48251	2.53100	.05838	.01000
142	.49000	.14922	1.15252	.01735	845.39366	2.54730	.04418	.01001
143	.50000	.14874	1.15384	.01106	861.20951	2.56826	.02620	.01001
144	.51000	.14813	1.15450	.00331	878.55010	2.59255	.00562	.01002
145	.52000	.14739	1.15442	-.00558	897.60027	2.62017	-.01713	.01003
146	.53000	.14652	1.15357	-.01567	918.52629	2.65370	-.04212	.01004
147	.54000	.14550	1.15194	-.02696	941.48663	2.70093	-.06962	.01006
148	.55000	.14434	1.14951	-.03956	966.63969	2.78037	-.09985	.01008
149	.56000	.14303	1.14630	-.05358	994.14977	2.93184	-.13245	.01009
150	.57000	.14158	1.14232	-.06920	1024.19206	3.23696	-.16565	.01012
151	.58000	.13999	1.13759	-.08663	1055.95703	3.85830	-.19469	.01014

LAMINAR SEPARATION OCCURS AT X= .59000

RTHT= 1092.65472 UT = 1.13214 XT= .59000 YT= .13824 BT = .168682E-01

OML2T = .00003 HT = 1.43109 CFT = .00037306 CDFL = .00064169

I	OML2	PSIL2	FLSL2	TH	H	SG	LOG(RTH)	CF
153	.00003020	.00022428	.00022094	.00004314	1.42726518	22.41900000	7.12602164	.00042476
154	.00003359	.00024961	.00025600	.00004794	1.42339642	22.77100000	7.24359472	.00047412
155	.00003702	.00027565	.00028051	.00005279	1.41989787	23.10100000	7.35209810	.00052131
156	.00004048	.00030177	.00031277	.00005772	1.41690937	23.41700000	7.45372322	.00056643
157	.00004401	.00032819	.00034709	.00006277	1.41446320	23.72300000	7.55013660	.00060956
158	.00004762	.00035492	.00038342	.00006794	1.41254839	24.02500000	7.64248837	.00065076
159	.00005131	.00038178	.00042331	.00007327	1.41115003	24.32400000	7.73170926	.00069008
160	.00005510	.00040940	.00046596	.00007877	1.41024778	24.62400000	7.81853768	.00072754
161	.00005900	.00043719	.00051221	.00008447	1.40982851	24.92800000	7.90359987	.00076319
162	.00006302	.00046536	.00056255	.00009039	1.40988492	25.23700000	7.98734181	.00079704
163	.00006717	.00049371	.00061754	.00009654	1.41041807	25.55300000	8.07029637	.00082912
164	.00007145	.00052267	.00057783	.00010296	1.41143416	25.87900000	8.15269733	.00085945
165	.00007588	.00055222	.00074412	.00010967	1.41294919	26.21600000	8.23499663	.00088806
166	.00008047	.00058197	.00081727	.00011669	1.41498571	26.56700000	8.31749013	.00091496
167	.00008523	.00061210	.00089822	.00012404	1.41757654	26.93300000	8.40032732	.00094018
168	.00009016	.00064261	.00098829	.00013177	1.42076464	27.31800000	8.48387507	.00096374
169	.00009527	.00067349	.00108815	.00013949	1.42460425	27.72400000	8.56832007	.00098568

170	.00010058	.00070473	.00014844	1.42916511	28.15500000	8.65387249	.00100602
171	.00010608	.00073631	.00015746	1.43453486	28.61500000	8.74072534	.00102480
172	.00011178	.00076821	.00016699	1.44082437	29.10800000	8.82905391	.00104204
173	.00011769	.00080043	.00017703	1.44817405	29.63900000	8.91901293	.00105780
174	.00012381	.00083294	.00018776	1.45676230	30.21700000	9.01073121	.00107210
175	.00013013	.00086573	.00019911	1.46681866	30.84900000	9.10436545	.00108499
176	.00013666	.00089880	.00021118	1.47864005	31.54800000	9.19978907	.00109652
177	.00014339	.00093212	.00022405	1.49261442	32.32700000	9.29717831	.00110674
178	.00015030	.00096570	.00023778	1.50925296	33.20700000	9.39639238	.00111571
179	.00015736	.00099952	.00025249	1.52923538	34.21400000	9.49724717	.00112347
180	.00016453	.00103358	.00026826	1.55347323	35.34500000	9.59942011	.00113010
181	.00017177	.00106766	.00028523	1.58319796	36.77000000	9.70240233	.00113566
182	.00017899	.00110213	.00030351	1.62008250	38.44400000	9.80543312	.00114021
183	.00018608	.00113695	.00032324	1.66639917	40.51500000	9.90740940	.00114385
184	.00019289	.00117161	.00034449	1.72519062	43.14100000	10.00676100	.00114666
185	.00019919	.00120616	.00036720	1.80032539	46.56200000	10.10129323	.00114873
186	.00020466	.00124030	.00039088	1.89594512	51.11800000	10.18805470	.00115018
187	.00020933	.00127435	.00041574	2.01990973	57.47600000	10.26468131	.00115112
188	.00021400	.00130840	.00043869	2.14387435	64.99200000	10.33669445	.00115170
189	.00021867	.00134244	.00046127	2.26783896	73.58100000	10.40309094	.00115204
190	.00022334	.00137649	.00048563	2.39180358	83.48200000	10.46461392	.00115222
191	.00022801	.00141053	.00051497	2.51576819	95.02000000	10.52194640	.00115231
192	.00023268	.00144458	.00055391	2.63973281	108.63800000	10.57554445	.00115234
193	.00023735	.00147863	.00060939	2.76369742	124.96700000	10.62582104	.00115234

HE = 2.76370 THE = .01082 OMLZE = .00024 PSILZE = .00148

ELSL2E= .00061 SHE= 2.58749 UE= .76103

CD IS THE DRAG COEFFICIENT BASED ON THE 2/3 POWER OF THE VOLUME
CD = .007877931
CS IS THE DRAG COEFFICIENT BASED ON THE WETTED AREA
CS= .001370866

PL = .1000E+08 J= 1 L= 1

I	X	Y	U	PGD	RTH	H	RDS	BETA	DS
2	.00100	.00474	.00759	.17494	45.47759	1.34060	60.96708	2.66065	.00448
3	.00200	.01236	.32645	.07977	51.93175	2.35816	122.46336	.28677	.00325
4	.00300	.01514	.38980	.65516	63.40018	2.40983	152.78352	.19019	.00272
5	.00400	.01749	.44016	.05216	72.75194	2.42061	176.10426	.17483	.00241
6	.00500	.01955	.48110	.04981	81.34836	2.42920	197.61109	.16340	.00220
7	.00600	.02142	.51699	.04802	89.37488	2.43580	217.69908	.15502	.00205
8	.00700	.02314	.54757	.04654	96.94033	2.44129	236.65924	.14829	.00194
9	.00800	.02475	.57447	.04525	104.12311	2.44608	254.69366	.14259	.00185
10	.00900	.02625	.59841	.04409	116.98209	2.45039	271.94955	.13760	.00177
11	.01000	.02768	.61991	.04304	117.56256	2.45433	288.53774	.13312	.00171
12	.01100	.02903	.63937	.04206	123.89999	2.45798	304.54384	.12906	.00166
13	.01200	.03033	.65759	.04115	130.02276	2.46138	320.03560	.12533	.00162
14	.01300	.03157	.67333	.04030	135.95390	2.46457	335.06756	.12190	.00158
15	.01400	.03277	.68827	.03950	141.71239	2.46756	349.68447	.11871	.00154
16	.01500	.03393	.70269	.03874	147.31414	2.47039	363.92381	.11574	.00151
17	.01600	.03504	.71491	.03803	152.77263	2.47307	377.81705	.11296	.00149
18	.01700	.03613	.72696	.03735	158.09934	2.47560	391.39105	.11036	.00146
19	.01800	.03718	.73801	.03670	163.30423	2.47801	404.66905	.10791	.00144
20	.01900	.03821	.74847	.03609	168.39595	2.48029	417.67123	.10561	.00142
21	.02000	.03922	.75829	.03550	173.38211	2.48247	430.41541	.10344	.00140
22	.02100	.04018	.76744	.03495	178.26946	2.48454	442.91731	.10138	.00139
23	.02200	.04113	.77627	.03441	183.06394	2.48651	455.19097	.09944	.00137
24	.02300	.04206	.78453	.03391	187.77104	2.48840	467.24899	.09760	.00136
25	.02400	.04297	.79235	.03342	192.39549	2.49020	479.10274	.09585	.00135
26	.02500	.04386	.79974	.03295	196.94171	2.49192	490.76251	.09418	.00133
27	.02600	.04474	.80645	.03251	201.41366	2.49356	502.23770	.09260	.00132
28	.02700	.04559	.81358	.03208	205.81500	2.49514	513.53689	.09110	.00131
29	.02800	.04643	.82001	.03167	210.14904	2.49665	524.66798	.08966	.00130
30	.02900	.04726	.82615	.03128	214.41884	2.49809	535.63823	.08829	.00129
31	.03000	.04808	.83257	.03090	218.62724	2.49948	546.45438	.08698	.00128
32	.03100	.04887	.83764	.03053	222.77634	2.50081	557.12265	.08573	.00128
33	.03200	.04966	.84334	.03018	226.87667	2.50209	567.64890	.08453	.00127

34	.03300	.05044	.84822	.02985	230.90919	2.50332	578.03839	.08339	.00126
35	.03400	.05120	.85320	.02952	234.89629	2.50449	588.29647	.08229	.00125
36	.03500	.05195	.85799	.02921	238.83334	2.50563	598.42771	.08124	.00125
37	.03600	.05269	.86261	.02891	242.72220	2.50672	608.43662	.08023	.00124
38	.03700	.05342	.86706	.02862	246.56459	2.50777	618.32733	.07926	.00124
39	.03800	.05415	.87136	.02834	250.36213	2.50878	628.10383	.07833	.00123
40	.03900	.05486	.87551	.02808	254.11635	2.50976	637.76987	.07743	.00122
41	.04000	.05556	.87952	.02782	257.82871	2.51069	647.32895	.07657	.00122
42	.04100	.05626	.88341	.02756	261.50055	2.51160	656.78445	.07575	.00121
43	.04200	.05694	.88717	.02732	265.13319	2.51247	666.13958	.07495	.00121
44	.04300	.05762	.89081	.02709	268.72784	2.51331	675.39729	.07418	.00121
45	.04400	.05829	.89434	.02686	272.28567	2.51413	684.56050	.07345	.00120
46	.04500	.05895	.89777	.02664	275.80778	2.51491	693.63199	.07273	.00120
47	.04600	.05960	.90110	.02643	279.29522	2.51567	702.61431	.07205	.00119
48	.04700	.06025	.90434	.02623	282.74901	2.51640	711.50996	.07139	.00119
49	.04800	.06089	.90749	.02603	286.17009	2.51711	720.32132	.07075	.00119
50	.04900	.06153	.91055	.02584	289.55937	2.51779	729.05065	.07013	.00118
51	.05000	.06215	.91353	.02565	292.91773	2.51846	737.70013	.06953	.00118
52	.05100	.06277	.91643	.02547	296.24600	2.51910	746.27196	.06896	.00118
53	.05200	.06339	.91926	.02530	299.54498	2.51972	754.76808	.06840	.00117
54	.05300	.06400	.92201	.02513	302.81544	2.52032	763.19036	.06786	.00117
55	.05400	.06460	.92470	.02497	306.05811	2.52090	771.54069	.06734	.00117
56	.05500	.06520	.92733	.02481	309.27369	2.52146	779.82085	.06684	.00116
57	.05600	.06579	.92989	.02466	312.46285	2.52200	788.03256	.06635	.00116
58	.05700	.06637	.93240	.02451	315.62626	2.52253	796.17747	.06588	.00116
59	.05800	.06695	.93484	.02436	318.76454	2.52304	804.25716	.06542	.00115
60	.05900	.06753	.93724	.02422	321.87828	2.52354	812.27312	.498	.00115
61	.06000	.06810	.93958	.02409	324.96806	2.52402	820.22687	.06455	.00115
62	.06100	.06866	.94187	.02395	328.03446	2.52449	828.11994	.06413	.00115
63	.06200	.06922	.94411	.02382	331.07800	2.52494	835.95362	.06373	.00115
64	.06300	.06978	.94630	.02370	334.09922	2.52539	843.72920	.06334	.00114
65	.06400	.07033	.94845	.02358	337.09860	2.52581	851.44801	.06296	.00114
66	.06500	.07088	.95056	.02346	340.07664	2.52623	859.11130	.06259	.00114
67	.06600	.07142	.95263	.02335	343.03340	2.52663	866.72027	.06223	.00114
68	.06700	.07196	.95465	.02323	345.97055	2.52702	874.27610	.06189	.00113
69	.06800	.07249	.95664	.02313	348.48732	2.52741	881.77981	.06155	.00113
70	.06900	.07302	.95859	.02302	351.78452	2.52778	889.23258	.06122	.00113
71	.07000	.07354	.96051	.02292	354.66258	2.52814	896.63575	.06090	.00113

72	.07100	.07497	.9623x	.02282	357.52191	2.52849	903.99014	.06059	.00113
73	.07200	.07458	.9642x	.02272	360.36298	2.52883	911.29655	.06029	.00112
74	.07300	.07510	.96604	.02262	363.18588	2.52916	918.55611	.05999	.00112
75	.07400	.07561	.96783	.02253	365.99125	2.52949	925.76997	.05971	.00112
76	.07500	.07611	.9695x	.02244	368.77938	2.52980	932.93890	.05943	.00112
77	.07600	.07661	.97130	.02235	371.55059	2.53011	940.06372	.05916	.00112
78	.07700	.07711	.97299	.02227	374.30522	2.53041	947.14536	.05890	.00112
79	.07800	.07761	.97466	.02218	377.04360	2.53070	954.18462	.05864	.00111
80	.07900	.07810	.97630	.02210	379.76604	2.53099	961.18229	.05839	.00111
81	.08000	.07859	.97791	.02202	382.47283	2.53126	968.13936	.05814	.00111
82	.08100	.07907	.97950	.02195	385.16430	2.53153	975.05668	.05790	.00111
83	.08200	.07955	.98107	.02187	387.84074	2.53180	981.93472	.05767	.00111
84	.08300	.08003	.98261	.02180	390.50241	2.53206	988.77423	.05745	.00111
85	.08400	.08051	.98412	.02172	393.14959	2.53231	995.57611	.05722	.00111
86	.08500	.08098	.98562	.02165	395.78256	2.53255	1002.34072	.05701	.00110
87	.08600	.08145	.98709	.02158	398.40155	2.53279	1009.06894	.05680	.00110
88	.08700	.08191	.98854	.02152	401.00684	2.53303	1015.76179	.05659	.00110
89	.08800	.08237	.98997	.02145	403.59869	2.53326	1022.41934	.05639	.00110
90	.08900	.08283	.99138	.02139	406.17729	2.53348	1029.04198	.05620	.00110
91	.09000	.08329	.99278	.02132	408.74290	2.53370	1035.63020	.05601	.00110
92	.09100	.08374	.99415	.02126	411.29569	2.53390	1042.18402	.05582	.00110
93	.09200	.08419	.99550	.02121	413.83585	2.53411	1048.70399	.05565	.00110
94	.09300	.08464	.99684	.02115	416.36358	2.53430	1055.18987	.05548	.00110
95	.09400	.08509	.99816	.02110	418.87899	2.53448	1061.63958	.05532	.00109
96	.09500	.08553	.99946	.02105	421.38212	2.53464	1068.04997	.05518	.00109
97	.09600	.08597	1.00075	.02102	423.87286	2.53475	1074.41292	.05508	.00109
98	.09700	.08640	1.00202	.02101	426.35069	2.53477	1080.70210	.05506	.00209
99	.09800	.08684	1.00328	.02108	428.91385	2.53456	1086.85365	.05525	.00109
100	.09900	.08727	1.00453	.01998	431.25793	2.53832	1094.67216	.05196	.00109
101	.10000	.08770	1.00564	.01849	433.80371	2.54345	1103.35962	.04750	.00109
102	.10200	.08855	1.00779	.01816	438.95227	2.54457	1116.94546	.04653	.00217
103	.10500	.08991	1.01006	.01829	446.41778	2.54412	1135.73937	.04693	.00325
104	.11000	.09185	1.01561	.01810	458.85765	2.54477	1167.68942	.04636	.00539
105	.12000	.09577	1.02510	.02019	482.05304	2.53763	1223.27345	.05256	.01070
106	.13000	.09949	1.03515	.02069	503.46757	2.53588	1276.73352	.05409	.01063
107	.14000	.10301	1.04390	.01907	524.60353	2.53838	1331.64522	.05191	.01057
108	.15000	.12635	1.51x7	.01954	545.29694	2.53985	1384.97439	.05063	.01052

109	.16000	.10952	1.05919	.01918	565.57011	2.54107	1437.15204	.04957	.01047
110	.17000	.11254	1.06596	.01886	585.46655	2.54217	1488.35801	.04861	.01042
111	.18000	.11541	1.67223	.01855	605.03300	2.54324	1538.74337	.04769	.01038

RTHN= 605.03300 PGPN= .01855 UN= 1.07223 XN= .18000 YN= .11541
RN= .144999E-02 IN= 111 CFN * .00008236

I	X	Y	U	PGP	RTH	H	RDS	BETA	DS
112	.19000	.11813	1.07806	.01824	624.31502	2.54430	1588.44498	.04677	.01035
113	.20000	.12072	1.08348	.01792	643.35569	2.54539	1637.58861	.04583	.01031
114	.21000	.12318	1.08854	.01758	662.19533	2.54651	1686.29026	.04485	.01028
115	.22000	.12551	1.09325	.01723	680.87152	2.54770	1734.65728	.04383	.01025
116	.23000	.12772	1.09765	.01686	697.41934	2.54896	1782.78950	.04274	.01023
117	.24000	.12981	1.10175	.01646	717.87160	2.55029	1830.77997	.04159	.01020
118	.25000	.13178	1.10556	.01604	735.25909	2.55170	1878.71566	.04038	.01018
119	.26000	.13364	1.10911	.01559	754.61076	2.55321	1926.67786	.03908	.01016
120	.27000	.13539	1.11241	.01511	772.95392	2.55480	1974.74255	.03771	.01014
121	.28000	.13703	1.11546	.01460	791.31437	2.55648	2022.98042	.03627	.01013
122	.29000	.13857	1.11828	.01407	809.71651	2.55825	2071.45675	.03476	.01011
123	.30000	.14000	1.12089	.01351	828.18333	2.56010	2120.23096	.03317	.01009
124	.31000	.14133	1.12328	.01292	846.73649	2.56202	2169.35574	.03153	.01008
125	.32000	.14256	1.12547	.01231	865.39617	2.56400	2218.87578	.02984	.01007
126	.33000	.14369	1.12747	.01169	884.18096	2.56602	2268.82576	.02811	.01006
127	.34000	.14472	1.12929	.01106	903.10758	2.56805	2319.22735	.02638	.01005
128	.35000	.14565	1.13095	.01044	922.19048	2.57006	2370.08487	.02467	.01004
129	.36000	.14650	1.13245	.00984	941.44125	2.57199	2421.37867	.02302	.01003
130	.37000	.14724	1.13381	.00928	960.46766	2.57377	2473.05509	.02151	.01002
131	.38000	.14790	1.13504	.00880	980.47236	2.57530	2525.01064	.02021	.01002
132	.39000	.14846	1.13617	.00845	1000.25071	2.57642	2577.06580	.01926	.01001
133	.40000	.14894	1.13722	.00830	1020.18741	2.57590	2628.91895	.01885	.01001
134	.41000	.14932	1.13823	.00847	1040.25074	2.57636	2680.05678	.01931	.01001
135	.42000	.14962	1.13925	.00917	1060.38175	2.57412	2729.54951	.02121	.01001
136	.43000	.14983	1.14035	.01087	1080.47071	2.56867	2775.37596	.02585	.01000
137	.44000	.14996	1.14168	.01439	1100.28267	2.55719	2813.63466	.03566	.01000
138	.45000	.15000	1.14345	.01955	1119.40015	2.53980	2843.05333	.05067	.01000
139	.46000	.14996	1.14576	.02380	1137.72247	2.52504	2872.79268	.06365	.01000
140	.47000	.14982	1.14828	.02462	1155.96517	2.52213	2915.49559	.06624	.01000

141	.48000	.14957	1.15062	.07210	1172.04531	2.53100	2974.03445	.05838	.01000
142	.49000	.14922	1.15252	.01735	1192.56718	2.54730	3045.46319	.04418	.01001
143	.50000	.14874	1.15384	.01100	1217.93416	2.56826	3127.97511	.02620	.01001
144	.51000	.14813	1.15450	.00331	1242.45746	2.59255	3221.13077	.00562	.01002
145	.52000	.14739	1.15442	-.00558	1269.39847	2.62017	3326.04261	-.01713	.01003
146	.53000	.14652	1.15357	-.01567	1294.49233	2.65370	3447.13217	-.04212	.01004
147	.54000	.14550	1.15194	-.02606	1331.46316	2.70093	3596.18729	-.06962	.01006
148	.55000	.14434	1.14951	-.03956	1367.03496	2.78037	3800.86159	-.09985	.01008
149	.56000	.14303	1.14630	-.05358	1405.94009	2.93184	4121.99441	-.13245	.01009
150	.57000	.14158	1.14232	-.06920	1448.42630	3.23696	4688.49408	-.16565	.01012
151	.58000	.13999	1.13759	-.08663	1494.76297	3.85830	5767.24024	-.19469	.01014

LAMINAR SEPARATION OCCURS AT X= .59000

RTHT= 1545.24712 UT = 1.13214 XT= .59000 YT= .13424 HT = .16A6A2E-01

OML2T = .00002 HT = 1.40757 CFT = .00026379 CDFL = .00045374

I	OML2	PSTL2	TH	FLSL2	H	SG	LOG(RTH)	CF
153	.00002195	.00016456	.00016081	.00003083	1.40240394	23.33800000	7.50150224	.00031150
154	.00002494	.00019221	.00018592	.00003496	1.39747897	23.73100000	7.64053319	.00035695
155	.00002793	.00021611	.00021210	.00003912	1.39318085	24.09500000	7.76564272	.00040033
156	.00003095	.00023998	.00023963	.00004332	1.38957787	24.43700000	7.88049880	.00044178
157	.00003401	.00026412	.00026679	.00004759	1.38663980	24.76300000	7.98761955	.00048135
158	.00003712	.00028847	.00029987	.00005194	1.38430745	25.08000000	8.08881148	.00051915
159	.00004028	.00031336	.00033318	.00005641	1.38253038	25.39000000	8.18543119	.00055523
160	.00004353	.00033749	.00036905	.00006101	1.38126472	25.69800000	8.27852450	.00058963
161	.00004685	.00036302	.00040786	.00006574	1.38047958	26.00600000	8.36892416	.00062238
162	.00005026	.00038842	.00045002	.00007065	1.38015293	26.31600000	8.45730690	.00065352
163	.00005377	.00041413	.00049600	.00007573	1.38027063	26.63200000	8.54423485	.00068305
164	.00005739	.00044015	.00054634	.00008101	1.38043081	26.95400000	8.63018970	.00071101
165	.00006113	.00046664	.00060163	.00008650	1.38183634	27.28500000	8.71558574	.00073742
166	.00006498	.00049311	.00066259	.00009223	1.38329985	27.62700000	8.80079046	.00076229
167	.00006897	.00052005	.00073002	.00009821	1.38524053	27.98200000	8.88613158	.00078566
168	.00007309	.00054717	.00080445	.00010448	1.38768673	28.35300000	8.97190732	.00080754
169	.00007735	.00057414	.00088816	.00011104	1.39067697	28.74100000	9.05839192	.00082795
170	.00008176	.00060235	.00098123	.00011702	1.39426078	29.15000000	9.14583876	.00084693

171	.00008633	.00063058	.00012515	.00108551	1.39850115	29.58400000	9.23448249	.00086449
172	.00009105	.00065884	.00013276	.00120273	1.40347852	30.04500000	9.32454035	.00088068
173	.00009594	.00068731	.00014078	.00133488	1.40929477	30.53900000	9.41621035	.00089552
174	.00010098	.00071599	.00014924	.00148430	1.41607949	31.07200000	9.50966799	.00090904
175	.00010619	.00074484	.00015818	.00165370	1.42399877	31.64900000	9.60506094	.00092129
176	.00011155	.00077385	.00016763	.00184620	1.43326701	32.28000000	9.70250042	.00093231
177	.00011706	.00080301	.00017765	.00206536	1.44416247	32.97500000	9.80204829	.00094213
178	.00012271	.00083230	.00018826	.00231017	1.45704939	33.75000000	9.90369992	.00095081
179	.00012846	.00086171	.00019954	.00240004	1.47240739	34.62300000	10.00736059	.00095839
180	.00013430	.00089122	.00021151	.00292459	1.49047109	35.61900000	10.11281389	.00096493
181	.00014017	.00092080	.00022425	.00329334	1.51328230	36.77400000	10.21967984	.00097049
182	.00014601	.00095043	.00023777	.00371022	1.54075616	38.13600000	10.32735934	.00097512
183	.00015173	.00098006	.00025212	.00417749	1.57475702	39.77200000	10.43496082	.00097889
184	.00015720	.00100958	.00026723	.00469425	1.61716149	41.77500000	10.54128368	.00098188
185	.00016224	.00103844	.00028295	.00525409	1.67022951	44.27300000	10.64429783	.00098417
186	.00016660	.00106757	.00029841	.00584187	1.73624234	47.43200000	10.74182177	.00098586
187	.00017030	.00109600	.00031484	.00644024	1.81999966	51.56600000	10.83218920	.00098702
188	.00017399	.00112444	.00032818	.00703860	1.90355698	56.19800000	10.91571205	.00098780
189	.00017769	.00115267	.00033984	.00763697	1.98721431	61.21600000	10.99199315	.00098829
190	.00018139	.00118130	.00035138	.00823537	2.07087163	66.66800000	11.06200765	.00098858
191	.00018509	.00120974	.00036510	.00893370	2.15452895	72.61000000	11.12673985	.00098873
192	.00018878	.00123617	.00038436	.00943206	2.23818627	79.11300000	11.18684383	.00098878
193	.00019248	.00126661	.00041423	.01003043	2.32184359	86.26000000	11.24288539	.00098878

HE = 2.32184   THE = .01003   UML2E = .00019   PSIL2E = .00127

ELSL2E= .00041   SHE= 2.15202   UE= .76103

CD IS THE DRAG COEFFICIENT BASED ON THE 2/3 POWER OF THE VOLUME
CD = .0070555AR
CS IS THE DRAG COEFFICIENT BASED ON THE WETTED AREA
CS= .001227767

134

RL = .15000E+08, I= 1, L= 1

I	X	Y	U	PGP	RTH	H	RDS	BETA	DS
2	.00100	.00874	.20759	.17494	55.69845	1.34060	74.66912	2.66065	.00448
3	.00200	.01236	.32685	.07077	63.60315	2.35816	149.98637	.28677	.00325
4	.00300	.01514	.38980	.05516	77.64904	2.40983	187.12083	.19019	.00272
5	.00400	.01748	.44016	.05216	89.10256	2.42061	215.68279	.17483	.00241
6	.00500	.01955	.48170	.04981	99.63098	2.42920	242.02317	.16340	.00220
7	.00600	.02142	.51699	.04802	107.46142	2.43580	266.62583	.15502	.00205
8	.00700	.02314	.54757	.04664	119.72717	2.44120	289.84719	.14829	.00194
9	.00800	.02475	.57447	.04525	127.52424	2.44608	311.93476	.14259	.00185
10	.00900	.02625	.59841	.04409	135.92475	2.45039	333.06882	.13760	.00177
11	.01000	.02768	.61991	.04304	143.98414	2.45433	353.38512	.13312	.00171
12	.01100	.02903	.63937	.04206	151.74588	2.45798	372.98851	.12906	.00166
13	.01200	.03033	.65719	.04115	159.24471	2.46138	391.96196	.12533	.00162
14	.01300	.03157	.67333	.04030	166.50884	2.46457	410.37228	.12190	.00158
15	.01400	.03277	.68827	.03950	173.56152	2.46756	428.27426	.11871	.00154
16	.01500	.03393	.70209	.03874	180.42224	2.47039	445.71382	.11574	.00151
17	.01600	.03504	.71491	.03803	187.10749	2.47307	462.72950	.11296	.00149
18	.01700	.03613	.72646	.03735	193.53135	2.47560	479.35418	.11036	.00146
19	.01800	.03718	.73851	.03670	200.06602	2.47801	495.61634	.10791	.00144
20	.01900	.03821	.74847	.03609	206.24207	2.48029	511.54069	.10561	.00142
21	.02000	.03920	.75829	.03550	212.34886	2.48247	527.14906	.10344	.00140
22	.02100	.04018	.76754	.03495	218.33461	2.48454	542.46070	.10138	.00139
23	.02200	.04113	.77627	.03441	224.20667	2.48651	557.49281	.09944	.00137
24	.02300	.04206	.78453	.03391	229.97162	2.48840	572.26081	.09760	.00136
25	.02400	.04297	.79235	.03342	235.63539	2.49020	586.77862	.09585	.00135
26	.02500	.04386	.79979	.03295	241.20335	2.49192	601.05887	.09418	.00133
27	.02600	.04474	.80685	.03251	246.68035	2.49356	615.11304	.09260	.00132
28	.02700	.04559	.81358	.03208	252.07046	2.49514	628.95167	.09110	.00131
29	.02800	.04643	.82001	.03167	257.37896	2.49665	642.58441	.08966	.00130
30	.02900	.04726	.82615	.03128	262.60838	2.49809	656.02018	.08829	.00129
31	.03000	.04808	.83242	.03090	267.76259	2.49948	669.26720	.08698	.00128
32	.03100	.04887	.83764	.03053	272.84479	2.50081	682.33311	.08573	.00128

135

#									
33	.03200	.04966	.84304	.03018	277.85796	2.50209	695.22508	.08453	.00227
34	.03300	.05044	.84822	.02985	282.80484	2.50332	707.94967	.08339	.00226
35	.03400	.05120	.85320	.02952	287.68802	2.50449	720.51308	.08229	.00225
36	.03500	.05195	.85799	.02921	292.50991	2.50563	732.92127	.08124	.00225
37	.03600	.05269	.86261	.02891	297.27277	2.50672	745.17963	.08023	.00224
38	.03700	.05342	.86706	.02862	301.97872	2.50777	757.29323	.07926	.00224
39	.03800	.05415	.87136	.02834	306.62973	2.50878	769.26695	.07833	.00223
40	.03900	.05486	.87551	.02808	311.22770	2.50976	781.10538	.07743	.00222
41	.04000	.05556	.87952	.02782	315.77439	2.51069	792.81281	.07657	.00222
42	.04100	.05626	.88341	.02756	320.27146	2.51160	804.39339	.07575	.00221
43	.04200	.05694	.88717	.02732	324.72051	2.51247	815.85104	.07495	.00221
44	.04300	.05762	.89081	.02709	329.12305	2.51331	827.18937	.07418	.00221
45	.04400	.05829	.89434	.02686	333.48047	2.51413	838.41196	.07345	.00220
46	.04500	.05895	.89777	.02664	337.79416	2.51491	849.52222	.07273	.00220
47	.04600	.05960	.90110	.02643	342.06539	2.51567	860.52328	.07205	.00219
48	.04700	.06025	.90434	.02623	346.29540	2.51640	871.41818	.07139	.00119
49	.04800	.06089	.90749	.02603	350.48535	2.51711	882.20985	.07075	.00219
50	.04900	.06153	.91055	.02584	354.63636	2.51779	892.90104	.07013	.00118
51	.05000	.06215	.91353	.02565	358.74949	2.51846	903.49445	.06953	.00218
52	.05100	.06277	.91643	.02547	362.82577	2.51910	913.99276	.06896	.00118
53	.05200	.06339	.91926	.02530	366.86618	2.51972	924.39833	.06840	.00117
54	.05300	.06400	.92201	.02513	370.87166	2.52032	934.71347	.06786	.00117
55	.05400	.06460	.92470	.02497	374.84310	2.52090	944.94050	.06734	.00117
56	.05500	.06520	.92733	.02481	378.78136	2.52146	955.08159	.06684	.00116
57	.05600	.06579	.92989	.02466	382.68728	2.52200	965.13884	.06635	.00116
58	.05700	.06637	.93240	.02451	386.56165	2.52253	975.11427	.06588	.00116
59	.05800	.06695	.93484	.02436	390.40523	2.52304	985.00983	.06542	.00115
60	.05900	.06753	.93724	.02422	394.21877	2.52354	994.82734	.06498	.00215
61	.06000	.06810	.93958	.02409	398.00297	2.52402	1004.56865	.06455	.00215
62	.06100	.06866	.94187	.02395	401.75852	2.52449	1014.23564	.06413	.00215
63	.06200	.06922	.94411	.02382	405.48609	2.52494	1023.82991	.06373	.00215
64	.06300	.06978	.94630	.02370	409.18630	2.52539	1033.35301	.06334	.00214
65	.06400	.07033	.94845	.02358	412.85978	2.52581	1042.80658	.06296	.00214
66	.06500	.07088	.95056	.02346	416.50712	2.52623	1052.19215	.06259	.00115
67	.06600	.07142	.95263	.02335	420.12889	2.52663	1061.51121	.06223	.00114
68	.06700	.07196	.95465	.02323	423.72566	2.52702	1070.76517	.06189	.00113
69	.06800	.07249	.95664	.02313	427.29795	2.52741	1079.95530	.06155	.00113

70	.06900	.07302	.95859	.02302	430.84629	2.52778	1089.08304	.06122	.00113
71	.07000	.07354	.96051	.02292	434.37117	2.52814	1098.15003	.06090	.00113
72	.07100	.07407	.96238	.02282	437.87312	2.52849	1107.15729	.06059	.00113
73	.07200	.07458	.96423	.02272	441.35259	2.52883	1116.10577	.06029	.00112
74	.07300	.07510	.96604	.02262	444.81004	2.52916	1124.99689	.05999	.00112
75	.07400	.07561	.96783	.02253	448.24591	2.52949	1133.83202	.05971	.00112
76	.07500	.07611	.96958	.02244	451.66065	2.52980	1142.61214	.05943	.00112
77	.07600	.07661	.97130	.02235	455.05468	2.53011	1151.33822	.05916	.00112
78	.07700	.07711	.97299	.02227	458.42840	2.53041	1160.01143	.05890	.00112
79	.07800	.07761	.97466	.02218	461.78222	2.53070	1168.63272	.05864	.00111
80	.07900	.07810	.97630	.02210	465.11651	2.53099	1177.20308	.05839	.00111
81	.08000	.07859	.97791	.02202	468.43164	2.53126	1185.72372	.05814	.00111
82	.08100	.07907	.97950	.02195	471.72801	2.53153	1194.19567	.05790	.00111
83	.08200	.07955	.98107	.02187	475.00596	2.53180	1202.61951	.05767	.00111
84	.08300	.08003	.98261	.02180	478.26582	2.53206	1210.99617	.05745	.00111
85	.08400	.08051	.98412	.02172	481.50795	2.53231	1219.32674	.05722	.00111
86	.08500	.08098	.98562	.02165	484.73266	2.53255	1227.61166	.05701	.00110
87	.08600	.08145	.98709	.02158	487.94026	2.53279	1235.85201	.05680	.00110
88	.08700	.08191	.98854	.02152	491.13108	2.53303	1244.04905	.05659	.00110
89	.08800	.08237	.98997	.02145	494.30542	2.53326	1252.20285	.05639	.00110
90	.08900	.08283	.99138	.02139	497.46356	2.53348	1260.31389	.05620	.00110
91	.09000	.08329	.99278	.02132	500.60576	2.53370	1268.38278	.05601	.00110
92	.09100	.08374	.99415	.02126	503.73228	2.53390	1276.40953	.05582	.00110
93	.09200	.08419	.99550	.02121	506.84333	2.53411	1284.39483	.05565	.00110
94	.09300	.08464	.99684	.02115	509.93915	2.53430	1292.33839	.05548	.00110
95	.09400	.08509	.99816	.02110	513.01990	2.53448	1300.23763	.05532	.00109
96	.09500	.08553	.99946	.02105	516.08559	2.53464	1308.08872	.05518	.00109
97	.09600	.08597	1.00075	.02102	519.13611	2.53475	1315.88171	.05508	.00109
98	.09700	.08640	1.00202	.02101	522.17082	2.53477	1323.58435	.05506	.00109
99	.09800	.08684	1.00328	.02108	525.18757	2.53456	1331.11843	.05525	.00109
100	.09900	.08727	1.00453	.01998	528.18094	2.53832	1340.69412	.05196	.00109
101	.10000	.08770	1.00564	.01849	531.29887	2.54345	1351.34404	.04750	.00109
102	.10200	.08855	1.00770	.01816	537.60454	2.54457	1367.97322	.04653	.00217
103	.10500	.08981	1.01086	.01829	546.74789	2.54412	1390.99097	.04693	.00325
104	.11000	.09195	1.01561	.01810	561.98355	2.54477	1430.12163	.04636	.00539
105	.12000	.09577	1.02530	.02019	590.39199	2.53763	1498.19789	.05256	.01070
106	.13000	.09949	1.03515	.02069	616.61933	2.53588	1563.67283	.05409	.01063
107	.14000	.10301	1.04390	.01997	642.50544	2.53838	1630.92566	.05191	.01057

RTHN= 642.50549 PGPN= .01947 UN= 1.04390 XN= .14000 YN= .10301

RN= .780211E-03 IN= 107 CFN # .00005112

I	X	Y	U	PGP	RTH	H	RDS	BETA	DS
108	.15000	.10635	1.05187	.01954	667.84963	2.53985	1696.24028	.05063	.01052
109	.16000	.10952	1.05919	.01918	692.67910	2.54107	1760.14459	.04957	.01047
110	.17000	.11254	1.06596	.01886	717.04715	2.54217	1822.85484	.04861	.01042
111	.18000	.11541	1.07223	.01855	741.01106	2.54324	1884.56805	.04769	.01038
112	.19000	.11813	1.07806	.01824	764.62662	2.54430	1945.43984	.04677	.01035
113	.20000	.12072	1.08348	.01792	787.94658	2.54539	2005.62826	.04583	.01031
114	.21000	.12318	1.08854	.01758	811.02034	2.54651	2065.27535	.04485	.01028
115	.22000	.12551	1.09325	.01723	833.89390	2.54770	2124.51261	.04383	.01025
116	.23000	.12772	1.09765	.01686	856.61025	2.54896	2183.46229	.04274	.01023
117	.24000	.12981	1.10175	.01646	877.20956	2.55029	2242.23838	.04159	.01020
118	.25000	.13178	1.10556	.01604	901.72954	2.55170	2300.94737	.04038	.01018
119	.26000	.13364	1.10911	.01559	924.20566	2.55321	2359.68883	.03908	.01016
120	.27000	.13539	1.11241	.01511	946.67135	2.55480	2418.55581	.03771	.01014
121	.28000	.13703	1.11546	.01460	967.15822	2.55648	2477.63489	.03627	.01013
122	.29000	.13857	1.11828	.01407	991.69614	2.55825	2537.00603	.03476	.01011
123	.30000	.14005	1.12089	.01351	1014.31329	2.56010	2596.74199	.03317	.01009
124	.31000	.14133	1.12328	.01292	1037.03618	2.56202	2656.90731	.03153	.01008
125	.32000	.14256	1.12547	.01231	1057.48953	2.56400	2717.55674	.02984	.01007
126	.33000	.14369	1.12747	.01169	1082.89610	2.56602	2778.73271	.02811	.01006
127	.34000	.14472	1.12929	.01106	1106.07638	2.56805	2840.46181	.02638	.01005
128	.35000	.14565	1.13095	.01044	1129.44806	2.57006	2902.74929	.02467	.01004
129	.36000	.14650	1.13245	.00984	1153.02534	2.57199	2965.57110	.02302	.01003
130	.37000	.14724	1.13381	.00928	1176.81774	2.57377	3028.86154	.02151	.01002
131	.38000	.14790	1.13504	.00880	1200.82849	2.57530	3092.49383	.02021	.01002
132	.39000	.14846	1.13617	.00845	1225.05192	2.57642	3156.24813	.01926	.01001
133	.40000	.14894	1.13722	.00830	1249.46930	2.57690	3219.75500	.01885	.01001
134	.41000	.14932	1.13823	.00847	1274.04176	2.57636	3282.38580	.01931	.01001
135	.42000	.14962	1.13925	.00917	1298.69711	2.57412	3343.00176	.02121	.01001
136	.43000	.14983	1.14035	.01087	1323.30096	2.56867	3399.12747	.02585	.01000
137	.44000	.14996	1.14168	.01439	1347.56556	2.55719	3445.98462	.03566	.01000

RTHT= 1347.56556 UT = 1.14168 XT= .44900 YI= .14996 HT = .104065E-01

OML2T = .00001 HT = 1.41655 CFT = .00016742 CDFL = .00029342

I	OML2	PSIL2	ELSL2	TH	H	SG	LOG(RTH)	CF
138	.00001464	.00011364	.00002054	.00009742	1.40260335	22.95800000	7.42116103	.00022165
139	.00001731	.00013669	.00002411	.00011524	1.39150373	23.39800000	7.59113299	.00027385
140	.00001987	.00015899	.00002753	.00013249	1.38272167	23.76100000	7.73279402	.00032442
141	.00002236	.00018048	.00003085	.00014944	1.37567646	24.07300000	7.85521509	.00037361
142	.00002482	.00020247	.00003411	.00016631	1.36992892	24.35100000	7.96386021	.00042157
143	.00002725	.00022348	.00003735	.00018330	1.36517210	24.60700000	8.06228850	.00046838
144	.00002968	.00024523	.00004060	.00020059	1.36119951	24.84800000	8.15299619	.00051410
145	.00003213	.00026661	.00004386	.00021832	1.35786692	25.07900000	8.23762765	.00055876
146	.00003460	.00028810	.00004718	.00023668	1.35507892	25.30200000	8.31762308	.00060238
147	.00003711	.00030978	.00005056	.00025541	1.35275838	25.52100000	8.39394064	.00064495
148	.00003968	.00033171	.00005403	.00027584	1.35084907	25.73800000	8.46736021	.00068647
149	.00004231	.00035395	.00005760	.00029705	1.34931139	25.95300000	8.53850530	.00072694
150	.00004501	.00037656	.00006128	.00031950	1.34811337	26.16900000	8.60787863	.00076634
151	.00004780	.00039958	.00006510	.00034341	1.34723175	26.38700000	8.67589470	.00080466
152	.00005069	.00042307	.00006907	.00036898	1.34664739	26.60800000	8.74289698	.00084187
153	.00005368	.00044704	.00007320	.00039641	1.34635012	26.83200000	8.80918119	.00087796
154	.00005679	.00047155	.00007751	.00042594	1.34633127	27.06100000	8.87499879	.00091292
155	.00006001	.00049661	.00008202	.00045783	1.34658607	27.29600000	8.94056924	.00094672
156	.00006337	.00052225	.00008674	.00049236	1.34711411	27.53700000	9.00608786	.00097935
157	.00006687	.00054850	.00009169	.00052984	1.34791873	27.78500000	9.07173098	.00101079
158	.00007052	.00057535	.00009688	.00057063	1.34900540	28.04200000	9.13765825	.00104103
159	.00007433	.00060284	.00010234	.00061511	1.35038341	28.30700000	9.20401794	.00107006
160	.00007831	.00063096	.00010809	.00066375	1.35206411	28.58400000	9.27094759	.00109788
161	.00008246	.00065972	.00011413	.00071703	1.35406426	28.87100000	9.33857975	.00112444
162	.00008680	.00068911	.00012051	.00077554	1.35640288	29.17100000	9.40703971	.00114977
163	.00009134	.00071915	.00012723	.00083994	1.35910328	29.48600000	9.47644858	.00117386
164	.00009609	.00074982	.00013433	.00091097	1.36219458	29.81600000	9.54692535	.00119671
165	.00010105	.00078111	.00014184	.00098948	1.36571121	30.16300000	9.61858602	.00121832
166	.00010623	.00081301	.00014977	.00107648	1.36969436	30.53000000	9.69154430	.00123869
167	.00011166	.00084552	.00015818	.00117308	1.37419293	30.91900000	9.76591101	.00125783
168	.00011733	.00087861	.00016708	.00128059	1.37926670	31.33200000	9.84179516	.00127574

169	.00012325	.00091227	.00017653	1.38498732	31.77300000	9.91930123	.00129245
170	.00012943	.00094648	.00018655	1.39144195	32.24600000	9.99852799	.00130796
171	.00013589	.00098122	.00019722	1.39873753	32.75600000	10.07956663	.00132229
172	.00014263	.00101648	.00020856	1.40700677	33.30700000	10.16249667	.00133546
173	.00014965	.00105225	.00022066	1.41641487	33.90800000	10.24738121	.00134749
174	.00015696	.00108849	.00023356	1.42717032	34.56700000	10.33426070	.00135842
175	.00016455	.00112520	.00024735	1.43953854	35.29500000	10.42314417	.00136827
176	.00017243	.00116237	.00026212	1.45386073	36.10800000	10.51399745	.00137707
177	.00018057	.00119998	.00027796	1.47058018	37.02300000	10.60672860	.00138486
178	.00018896	.00123802	.00029498	1.49027855	38.06800000	10.70116737	.00139169
179	.00019757	.00127647	.00031333	1.51372694	39.27700000	10.79703928	.00139758
180	.00020635	.00131532	.00033315	1.54195800	40.69900000	10.89393005	.00140259
181	.00021524	.00135455	.00035463	1.57636807	42.40300000	10.99123730	.00140677
182	.00022414	.00139409	.00037795	1.61886004	44.48900000	11.08810296	.00141017
183	.00023290	.00143388	.00040333	1.67203264	47.10600000	11.18334750	.00141286
184	.00024134	.00147377	.00043093	1.73938920	50.47700000	11.27518640	.00141491
185	.00024918	.00151355	.00046072	1.82539843	54.94400000	11.36365564	.00141640
186	.00025600	.00155285	.00049213	1.93475585	61.01200000	11.43879483	.00141741
187	.00026184	.00159264	.00052533	2.07586985	69.65400000	11.50483436	.00141805
188	.00026768	.00163123	.00055753	2.21698384	80.07800000	11.56774098	.00141843
189	.00027353	.00167042	.00059082	2.35809784	92.29400000	11.62629989	.00141865
190	.00027937	.00170961	.00062789	2.49921183	106.80200000	11.68091455	.00141876
191	.00028522	.00174861	.00067267	2.64032583	124.31500000	11.73213932	.00141881
192	.00029106	.00178800	.00073081	2.78143982	145.88600000	11.78029861	.00141883
193	.00029690	.00182719	.00081061	2.92255382	173.14800000	11.82570114	.00141883

HE = 2.92255 THE = .01148 UML2E = .00030 PSIL2E = .00183

ELSL2E= .00081 SHE= 2.73022 UE= .76103

CD IS THE DRAG COEFFICIENT BASED ON THE 2/3 POWER OF THE VOLUME
CD = .009478812
CS IS THE DRAG COEFFICIENT BASED ON THE WETTED AREA
CS= .001649441

REFERENCES

1. Granville, P. S., "The Calculation of the Viscous Drag of Bodies of Revolution," David Taylor Model Basin Report 849 (Jul 1953).

2. Granville, P. S., 'The Prediction of Transition from Laminar to Turbulent Flow in Boundary Layers on Bodies of Revolution," NSRDC Report 3900 (Sep 1974); also presented at the Tenth Office of Naval Research Symposium on Naval Hydrodynamics, Massachusetts Institute of Technology, Cambridge, Mass. (Jun 1974) and will appear in the proceedings of this symposium.

3. Smith, A. M. O., Discussion of Granville symposium paper[2]; will appear in the symposium proceedings.

4. Granville, P. S., "Similarity-Law Method for Thick Axisymmetric Turbulent Boundary Layers in Pressure'Gradients," DTNSRDC Report 4525 (in preparation).

5. Nakayama, A. and V. C. Patel, "Calculation of the Viscous Resistance of a Body of Revolution," Journal of Hydronautics, Vol. 8, No. 4, pp. 154-162 (Oct 1974).

6. Cebeci, T. et al., "Calculation of Viscous Drag in Incompressible Flows," Journal of Aircraft, Vol. 9, No. 10, pp. 691-692 (Oct 1972).

7. Parsons, J. S. et al., "Shaping of Axisymmetric Bodies for Minimum Drag in Incompressible Flows," Journal of Hydronautics, Vol. 8, No. 3, pp. 100-107 (Jul 1974).

8. Lugt, H. J. and S. K. Oh, "Boundary-Layer Suction with Slots on Axisymmetric Bodies," NSRDC Report 4038 (Nov 1972).

9. Thwaites, B., "Approximate Calculation of the Laminar Boundary Layer," Aeronautical Quarterly, Vol. I, Part III, pp. 245-280 (Nov 1949).

10. Lighthill, M. J., "On Displacement Thickness," Journal of Fluid Mechanics, Vol. 4, Part 4, pp. 383-392 (Aug 1958).

11. "360 Scientific Subroutine Package, Version III," IBM Reference Manual, Serial H-20-0205-3, p. 319 (1968).

12. Hess, J. L. and A. M. O. Smith, "Calculation of Potential Flow about Arbitrary Bodies," in "Progress in Aeronautical Sciences," Pergamon Press, Oxford and New York, Vol. 8, (1966), pp. 1-138.

13. White, F. M., "Viscous Fluid Flow," McGraw-Hill Book Company, New York (1974).

14. Carmichael, B. H., "Underwater Drag Reduction through Choice of Shape," American Institute of Aeronautics and Astronautics Paper 66-657 (1966).

15. Carmichael, B. H., "Underwater Drag Reduction through Optimum Shape," in "Underwater Missile Propulsion," edited by Leonard Greiner, Compass Publications, Arlington, Virginia (1967), pp. 147-169.

16. Young, A. D., "The Calculation of the Total and Skin Friction Drags of Bodies of Revolution at Zero Incidence," British Aeronautical Research Committee Reports and Memoranda 1874 (Apr 1939).

17. McCarthy, J. H. et al., "The Roles of Transition, Laminar Separation, and Turbulence Stimulation in the Analysis of Axisymmetric Body Drag," DTNSRDC Report 4728 (in review).

18. Granville, P. S., "Geometrical Characteristics of Streamlined Shapes," NSRDC Report 2962 (Mar 1969); also Journal of Ship Research, Vol. 13, No. 4, pp. 299-313 (Dec 1969).

19. Landweber, L. and M. Gertler, "Mathematical Formulation of Bodies of Revolution," David Taylor Model Basin Report 719 (Sep 1950).

20. Granville, P. S., "Geometrical Characteristics of Noses and Tails for Parallel Middle Bodies," NSRDC Report 3763 (Dec 1972); also International Shipbuilding Progress, Vol. 21, No. 233, pp. 3-19 (Jan 1974).

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